UNIVERSITY OF ALBERTA

# *FORESTED LANDSCAPE PATTERNS IN THE WESTERN BOREAL MIXEDWOOD FOREST OF ALBERTA: Riparian Forests, Fire History, Canopy Composition and Topography*

by

Carl James Burgess ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

in

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled *FORESTED LANDSCAPE PATTERNS IN THE WESTERN BOREAL MIXEDWOOD FOREST OF ALBERTA: RIPARIAN FORESTS, FIRE HISTORY, CANOPY COMPOSITION AND TOPOGRAPHY* submitted by Carl J. Burgess in partial fulfillment of the requirements for the degree of MASTERS OF SCIENCE in ENVIRONMENTAL BIOLOGY AND ECOLOGY.

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## ABSTRACT

The purpose of this study was to explore the landscape-scale factors that influence the age and composition of riparian forests in western boreal mixedwood landscapes of Alberta.

Adjacency to lakes (5-100ha) did not significantly influence the time-since-fire and canopy composition of forested riparian regions (up to 600m from open bodies of water) across broad landscapes. However, there was a relationship between topographic orientation (an indirect estimation of local/regional groundwater, spring thaw dynamics and micro-climate) and time-since-fire distributions. This is counter to the conventional understanding of wildfire ecology which assumes the mild topographic relief of boreal landscapes to be of little influence on regional or local fire frequency. The spatial distribution of dominant tree species was related to physiography at a local scale.

The correspondence of forest age and tree species composition with topography reflects processes which are observable at different scales; tree composition is influenced most by local topographic variation while the time-since-fire distribution is influenced most by regional topography. This difference implies that there is a mechanistic independence between the spatial distribution of tree species and burn patterns. Therefore, the mosaic of canopy composition may be spatially nested within the time-since-fire mosaic, suggesting that the combined landscape pattern is spatially static over a longer period than generally assumed. In short, across broad tracts of forest, wildfire "resets" successional

development at specific locations but the mosaic of canopy composition is relatively constant.

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For everybody who has made my latest travels such a great experience, especially Sam, my memories are alive and fun. To the dimensionless support of my family, your love and friendship has kept me sane against all my attempts to derail. Andrea, my field assistant, thanks partner. Your enthusiasm lightened the load. Cheers to those who are Friends of Pedon and to the Organization of Botany Students.

My hope is that the special place that has brought us together, the boreal forest, remains, with all its different faces, so that future generations will walk our paths and see all our stories. I also hope that I contribute to that.

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# CHAPTER 1

## *General Introduction and Thesis Outline*

### *1.1 Introduction*

Wildfire is considered the dominant natural disturbance occurring throughout Canada's boreal forests (Rowe and Scotter 1973, Rowe 1983, Wein and Maclean 1983, Van Wagner 1990, Johnson 1992). Much research has been conducted regarding many aspects of fire ecology, post-fire regeneration and behaviour; both in Canada and internationally (Van Wagner 1990). In the boreal forests of Canada, the combination of wide extents of coniferous forests (a forest fuel considered highly flammable), and extreme summer weather patterns, creates conditions for high intensity wildfires to occur relatively frequently (Chandler *et al.* 1983, Forestry Canada 1992, Johnson 1992). Fire is estimated to be as frequent as every 50-200 years in much of the boreal (Rowe and Scotter 1973, Johnson 1992).

The temporal pattern of fire occurrence is dependent on climatic conditions (Johnson 1992). Climate and weather patterns greatly influence the timing and behavior of specific burn events (Chandler *et al.* 1983, Johnson 1992). Undeniably, both regional and continental weather patterns are associated with the overall frequency and severity of fire events (Balling *et al.* 1992, Johnson and Wochuck 1993).

The distribution of area covered by different forest age classes (or time-since-fire distributions) of a given landscape is considered to be indicative of the stand replacing fire history that occurred within that landscape (Heinselman 1973, Van Wagner 1978, Johnson 1979, Johnson and Gutsell 1994). Forest age

class distributions, as represented in map form, are the basis of many fire regime modeling efforts (see Francis 1996). Fitting the cumulative area covered by each age class to negative exponential and Weibull distributions, we can estimate parameters such as return interval, annual percent burn, and average prospective life time to characterize a region's fire regime (Masters 1990, Johnson *et al.* 1990, Clark 1990, Johnson and Larsen 1991). Assumptions that fire occurrences are spatially random, forest vegetation mosaics do not limit fire spread in dry conditions, and that topography does not influence long-term fire frequency are required to accurately apply these models and generate estimations of fire regimes.

Other studies, however, have demonstrated relationships between landform and the fire history of a region (Suffling 1982, Swanson *et al.* 1988, Francis 1996, Andison 1997). Such findings have generated concern regarding the assumption of spatially random/independent fire behaviour across forested landscapes inherent in the above mentioned models (see Baker 1989, Turner and Romme 1994, Rogeau 1995, Francis 1996). Also, topography has been demonstrated to affect the behaviour of specific fire events and regional fire histories (Chandler *et al.* 1983, Bergeron 1991). It may seem intuitive that immediate landform characteristics may affect wildfire behaviour and frequency but this spatial relationship has not been included in the prevailing understanding of boreal fire ecology.

The spatial context of ecological processes that occur, and are only observable, at broad scales has not been the focus of many research efforts in this discipline. A better understanding of the spatio-temporal of ecological processes (specifically fire in boreal systems) is required.

### *1.2 Ecosystem Management and the TROLS Project*

Aldo Leopold's (1966) first principal of intelligent tinkering states that all parts must be retained. As insightful and poignant as this is, we still must continue to fill in what can be read between the lines. We must leave examples of what we are tinkering with and examine the way we tinker. As well, we must leave the post-tinkered piece in a readily accessible state because we are not sure in what order, or how fast, we must put the pieces together, or what they need to put themselves back together. To this end, landscape ecology is a discipline which offers a different context with which to assess our understanding of, and actions within, ecosystems. Generally, landscape ecology addresses questions relevant to the observation and interpretation of broader landscapes. It is considered a critical tool to help ensure that extractive development within an ecosystem are appropriately arranged in space and time.

As applied to forest resource management in Canada's boreal forest, ecosystem-based management strategies attempt to design and implement forest harvest systems which ensure that the ecological functions and processes that occur across boreal landscapes continue. Initially, these strategies use estimates of natural disturbance regimes of a landscape as a working model for harvest strategies (Franklin and Forman 1987, Hunter 1993, Franklin 1993, Larsen *et al.* 1997). As a preliminary step to developing a truly adaptive and sustainable harvest, our basic understanding of boreal forest ecology, especially vegetation-disturbance dynamics, must be revisited and assessed before, and while, they are employed to guide and evaluate harvest practices.

A specific issue regarding Alberta's (and other) forest harvest regulations is the use and effect(s) of riparian buffer-strips. Concerns relate to the relatively arbitrary nature and narrow ecological focus of regulatory post-harvest riparian buffer strips. To provide a scientific basis for buffer strip policy and management, the interdisciplinary project called Terrestrial Riparian Organisms Lakes and

Streams (TROLS) was developed as a co-operative effort of commercial harvest operators, government, and university researchers. Using experimental harvest designs which incorporate various buffer-strip widths, the overall objective is to assess the role and influence this practice has within western boreal mixedwood forest ecosystems. This thesis is an attempt to provide a broader landscape context and ecological setting to evaluate and describe riparian forest regions. The broader ecological setting (with noted terrestrial bias) is assumed to be, and measured using, a combination of fire history and the spatial pattern of tree species which occur in the region.

Those who assume the responsibility for planning and managing public lands within the boreal mixedwood forest require information regarding the temporal and spatial patterns present in these ecosystems. To consider that one dimension of pattern (space or time) has precedence over the other in land management, across all scales, is faulty logic and risks potential long-term and/or adverse effects. The following information considers both temporal and spatial patterns of a boreal mixedwood landscape at a spatial scale similar to the extent of forests used for site specific resource planning in north-central Alberta.

### *1.3 Sources of Digital Data*

Three sources of baseline data have been used for this thesis: the Alberta Vegetation Inventory (A.V.I.), a digital elevation model (D.E.M.), and lightening strike data (L.S.D.). Chapter Four will discuss the nature and use of the lightning strike information and the D.E.M. in more detail. The digital information that exists regarding large regions of Alberta's forested land-base is a unique resource for those who are interested in exploring ecological phenomena observable at a landscape scale. However, these data are usually developed for specific purposes and users. Therefore, before such data can be used for research purposes, the accuracy needs to be quantitatively assessed to ensure its appropriate use and interpretation (see Aspinall 1995).

Generally, all data sources can be combined and/or manipulated in a geographic information system (G.I.S.) to develop digitally represented landscapes and data bases. This allows for a more accurate expression of the complexity of forested landscapes than each data set would on its own. However, it is also possible to focus on specific attributes of land-based inventories to address a specific problem (e.g. land-use conflicts, road construction) or explore specific phenomena (e.g. cumulative removal of different habitat types, spatially variable growth rates of tree species). This project focuses on the spatial distribution of dominant tree species and age-class to explore the organizational tendencies of forest spatial patterns in response to topography.

### *1.4 The Alberta Vegetation Inventory*

The first generation of the A.V.I. records continuously forested landscapes as a resource and harvest planning aid. Initially developed from 1:15,000 air-photographs of forested landscapes, the inventory has improved upon earlier efforts (Alberta "Phase-Three" forest inventories) by using a more consistent protocol and helicopter surveyed post-inventory ground-truthing (Joy 1994, Sandvoss Inventory Forester, Pearson Timberline Forestry Consultants *per. comm.* 1996).

For each identifiable stand on the forested land-base, including peatlands, numerous attributes are estimated including crown closure, height, tree species composition (up to three dominant tree species), stand structure, understory type, drainage class, and decade-of-origin. The stand resolution has been estimated at ~0.4ha (Joy 1996). Age classifications are based on height versus age regressions, for each species within the inventoried region. Species are classified using canopy signatures identifiable from aerial photographs.

The Geographical Information System (G.I.S.) that was used to combine and query the data was the Geographical Resources Analysis Support System (GRASS) and *r.le* (landscape ecology) programming (Baker 1994). This system and technical support was available at the University of Alberta. The main advantage of the GRASS platform is its ability to import a variety of data developed within other G.I.S. packages. All data were converted from the original platforms into separate GRASS raster (matrix of pixel data) maps.

### *1.5 Defining Scale*

The term *scale* can be problematic in that it is ambiguous and may misguide understandings of a two-dimensional plane of data (see Meentemeyer and Box 1987, Turner *et al.* 1989, Allen and Hoekstra 1990). Generally, scale is a measure or description of the quantity and quality of an observation. Concepts used to assess the nature and quality of a two-dimensional plane of data are resolution, discrimination and extent (Turner *et al.* 1989). The resolution (or grain) of data is considered the smallest homogeneous portion of a landscape detectable (e.g. individual trees $<25m^2$ versus entire forest stands $>500m^2$). The extent is the continuous area that is observed at a given time. Discrimination is the ability to differentiate properties (e.g. identifying tree species from canopy signatures) within a landscape given the extent and resolution of the information.

The resolution and extent of data are dependent on the processes of detection (e.g. satellite imagery, aerial photographs) and interpretation (e.g. standardized visual assessment, supervised classification) and as such can only be reduced in detail. In short, the grain size of a spatial data set can only be increased, not decreased for accurate research applications. However, the ability to discriminate between and within specific attributes can be assessed through predictive tests and ground-truthing of the data.

### *1.6 Thesis Outline and Objectives*

The objectives of this project were: ***1)*** to assess how ecologically unique, in terms of canopy composition and age, riparian forests adjacent to moderately sized lakes are within Alberta's mixedwood boreal region, ***2)*** to develop a broader scale context of boreal landscape structure of canopy composition and wildfire spatio-temporal patterns. The focus of each subsequent chapter is outlined below.

***Chapter 2:*** *Assessing the use of the Alberta Vegetation Inventory as Fire History Data*

Digital forest inventory data (Alberta Vegetation Inventory, A.V.I.) is available for large extents of Alberta's mixedwood boreal forest. In order to use this resource as ecological data, a field survey was conducted to assess the extent to which stand origin estimates reflected actual time-since-fire distributions. This chapter presents the technique and findings of this survey which demonstrate that the spatial pattern of age-classes estimated in the Alberta Vegetation Inventory (A.V.I.) are representative, within limits, of the actual time-since-fire mosaics.

***Chapter 3:*** *Are riparian forests unique within Aspen dominated mixedwood landscapes?*

Chapter 3 discusses a comparison, conducted in a simulated GIS environment, of time-since-fire distributions and dominant canopy species, between areas adjacent to open water bodies and that of local upland regions. Neither the dominant age class nor dominant tree species were found to be influenced by adjacency to open water. As such, forests adjacent to water are not as consistently different, in terms of canopy composition and age, from the surrounding landscape as we might generally assume.

***Chapter 4:*** *Landscape Patterns in the Western Boreal Mixedwood Forest*

Chapter 4 is an effort to assess the spatial and temporal organization of the mixedwood boreal forest landscape. Specifically, I examined the association between spatial time-since-fire mosaics, canopy composition mosaics, and topography. This research used a forested region of similar size to that for which the majority of forest harvest plans, operations, and regulations apply. This chapter will demonstrate that elevation and landform are associated with both time-since-fire and dominant tree species distributions. Topographic variation is associated with previously described trends of these two forest attributes, at different spatial scales.

Elevation and landform are associated with both time-since-fire and dominant tree species distributions. Topographic variation is associated with trends of these two attributes at different spatial scales. Considering the scale of these observations, the findings support the following: ***1)*** the history of stand-replacing fires is independent of the spatial pattern of tree species (i.e. differential fuel types), ***2)*** potentially, fire regimes may operate differently among different elevation classes of a landscape. Therefore, at such a scale, fire occurrences may not be spatially random, and ***3)*** unidirectional interpretations of forest succession in the western boreal mixedwood, which generally assume a disturbed forest stand will progress through a deciduous "pioneer" community into a confer dominated "climax" community, may be misleading models when used to explain the dynamics of the mixedwood boreal forest mosaic at a landscape.

**Chapter 5:** *Conclusions, Recommendations and Future Directions*

Chapter 5 summarizes the thesis conclusions and makes further recommendations and suggestions for further work in this area.

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# CHAPTER 2

## *Assessing the use of the Alberta Vegetation Inventory as Fire History Data*

### *2.1 Introduction*

Landscape scale investigations are becoming increasingly important for ecological research. The recent ability of researchers to incorporate extensive landscapes of continuous data (i.e. two dimensional planes of data for use in Geographic Information Systems) into inquiries is advantageous in that it can provide a broader spatial context of ecological information and understandings. Also, we can now address questions related to the patterns and phenomena that emerge with increasing extents of observation. With an increasing interest in landscape approaches to understanding ecosystems, such research is becoming more dependent on remote sensing and spatial analysis techniques. More specifically, this analysis usually employs some form of geographic information system (G.I.S.).

Recently, the increased economic, political, ecological and academic attention on boreal mixedwood forest regions of Alberta has spurred the development of landscape inventories to accommodate various needs related to forest resources (Anon. 1985, Anon. 1991). These inventories, chiefly the Alberta Vegetation Inventory (A.V.I.), have been developed on geographic information systems (G.I.S.). Such systems can provide powerful resource management tools, flexible visual representations, and allow for a diverse range of analytical approaches. However, in order to appropriately capitalize on the

latter, an assessment of the accuracy and bias inherent in the data must be conducted.

Developing fire history information for forested regions is an extremely time and resource consuming process. However, the need to incorporate disturbance regime information into forest resource planning is paramount if we are to develop truly sustainable harvest strategies and minimize the ecological impact of commercial logging within boreal ecosystems. The recent expansion of large scale forest resource development in Canada's western mixedwood boreal forest has not included specific landscape understandings of wildfire behaviour and spatial pattern.

The development of detailed forest resource inventories such as the A.V.I. may provide a data base which can greatly help researchers develop a quantification of boreal fire history and long term spatial tendencies. Should the A.V.I. prove to reliably estimate the time-since-fire distributions of the forested landbase, it will be possible to develop spatially explicit fire history information and explore the potential associations between fire history, landform, climatic variation, and human interactions over very large areas. This chapter will assess how well the A.V.I. decade-of-origin data represent the study area's wildfire history.

The actual time-since-fire of forest stands of the oldest classes may be older than inventory estimates given the inherent bias of using tree age as representative of time-since-fire (see Fox 1989, Finney 1995). However, as a result of relatively high wildfire frequencies, many forest stands across boreal landscapes are dominated by a single age cohort (Rowe and Scotter 1973, Van Wagner 1990). This tendency to form a single age cohort make assessments of historical disturbance patterns easier and reduces the number of underestimated time-since-fire classes than in other forest regions where more stands exhibit multiple species and age cohorts. Fire boundaries in boreal areas create strong

canopy juxtapositions of species and/or stand age for extended periods of time. I focused on edges, identified as the delineation between adjacent A.V.I. stands, to examine the validity of using the inventory's decade-of-origin data to express the historical pattern(s) of wildfire events (see Wiens *et al.* 1985). A stand is defined as a treed "patch" that is different in terms of species composition, height, age and/or density from the immediately surrounding area.

### *2.2 Objectives*

Other versions of these forest inventory data have been used for ecological inquiries (Cumming and Pelletier 1995, Cumming *et al.* 1996, Rettie *et al.* in press) across boreal landscapes. However, there is little information regarding the use of decade-of-origin information as a time-since-fire mosaic. The goal of this project was to quantify how well the A.V.I. decade-of-origin estimates reflect historical stand replacing wildfire (Fig. 2.1). Three specific objectives were: ***1)*** to test the accuracy of the decade of origin assessments of the A.V.I., ***2)*** to explore the validity and limitations of the A.V.I. decade-of-origin estimations as a time-since-fire record, and, ***3)*** to determine the predictability of finding a boundary of past fire event(s) associated with the age and/or species boundaries delineated in the A.V.I.. Two assumptions were required for this project: ***1)*** the majority of the forested land-base is of fire origin, and ***2)*** the spatial patterns observed on the forested landscape, as represented by the A.V.I., are the result of mechanisms little affected by human activities.

### *2.3 Study Area*

Two regions were used in this inquiry; one south of Calling Lake and the other north of Lac La Biche, Alberta. Together they consist of eleven townships[1] (10x10km/twp) and include ~82,000ha of forested land. These areas are the regions which had complete A.V.I. coverage and are under study by the TROLS project. To provide a larger land-base for inquiry, additional areas adjacent to the study area with A.V.I. coverage were included to total eleven townships. All regions are typical of southern boreal mixed-wood landscapes in Alberta, which include; trembling aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), white spruce (*Picea glauca*), black spruce (*Picea mariana*), tamarack (*Larix laricina*), paper birch (*Betula papyrifera*), jack pine (*Pinus banksiana*) and balsam fir (*Abies balsamea*). All forested areas given an A.V.I. estimate of decade-of-origin were considered in the survey.

[1] Townships included in the survey conducted for this chapter include T70-R11, T71-R11, T71-R12, T71-R13 and T72-R11, north of Lac La Biche, Alberta, and T70-R25, T71-R24, T71-R25, T72-R24, T72-R25 and T73-R24 south of Calling Lake, Alberta.

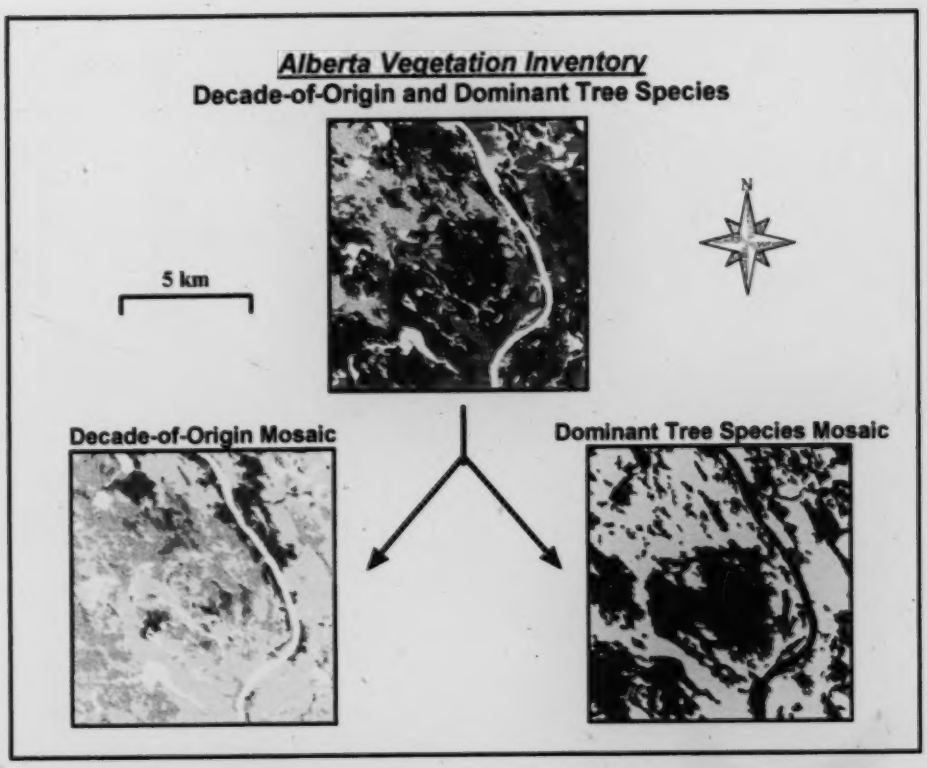



**Figure 2.1:** A decomposition of the original age/species mosaic into separate map-sheets showing only the decade-of-origin and dominant tree species landscape attributes. Generated from Alberta Vegetation Inventory (1996) of Township 70 Range 24, Alberta.

### *2.4 Methods*

The A.V.I. decade of origin estimates are reported to be accurate within ten years (Anon. 1991). To test this accuracy, a minimum of three cores/trees per stand were taken (April-June 1995) from 112 stands dispersed throughout the study area. Stands dominated by all the dominant canopy tree species occurring within the study area were sought. Twelve age classes, grouped into decades of origin, spanning from 1860 through to 1960 were sampled. In order to sample the dominant canopy on which the A.V.I. estimates were based, sampled trees were chosen that represented the dominant height and DBH of each sampled stand. The A.V.I.-estimated stand age was then tested against the observed age per stand to asses the reliability of the AVI decade of origin estimate and explore for possible species-dependent bias.

To record evidence of past fire events that were associated with the A.V.I. stand edges, decade of origin differences ranging from zero (adjacent stands with the same A.V.I. age but different dominant species) to 80 years (adjacent stands with different age, same or different species) were surveyed in the field. Along each edge, transects at least 100m long and 15m wide on either side of the A.V.I. delineated edge were searched. 15m wide transect was used to the A.V.I. delineated area was directly searched. All evidence of fire events were recorded and all obvious fire scars were tallied and cored to assess the actual date of the fire event. Coring protocols were developed from Barrett and Arno (1988) and Johnson and Gutsell (1994). In total, 181 A.V.I. delineated edges (>100m long) were surveyed. Varied species juxtapositions were sought per age class difference.

After the field surveys were completed, each sampled edge was classed either as, **1**, absolutely associated with evidence of a past fire event, or **0**, inconclusive and therefore classed as not associated with a fire event. To be

classed as being associated with a past fire event, an edge had to have: ***1)*** obvious fire scars along the edge, ***2)*** an obvious difference in shrub burning (i.e. numerous exposed and burnt root crowns[2]) between stands on either side of the AVI edge and/or ***3)*** fire scarring along the edge which back-dated a fire event that corresponded to the age of the younger stand's dominant cohort. With this dichotomous classification, a logistic regression model was generated to express the probability with which an A.V.I. delineated difference in decade-of-origin predicted a fire event. A breakdown of the A.V.I. decade of origin accuracy by stand-dominant species was also developed to explore the potential for species-dependent bias in decade of origin error.

Finally, to help assess the use of the edges as representative of the A.V.I. age pattern, the distribution of age juxtapositions was generated (see *r.le* and *r.edges* sub-programming that are developed for use with GRASS GIS platforms; see Baker 1994). The distribution of age juxtapositions, as a percent of the total length of age-related edges, were quantified for the entire study area.

### *2.5 Results*

Generally, the A.V.I. decade of origin estimates were found to be as accurate as reported by the developers (Pearson Timberline Forestry Consultants). Nine (75%) of the 12 sampled age classes were within the reported error margin of ten years (see Fig. 2.2). However, the standard deviation of the observed ages increases slightly with increasing A.V.I.-estimated decade of origin suggesting that more of the older A.V.I. age classes were incorrectly estimated. Overall, 64% of examined stands were within the reported error (10 years) of the AVI decade of origin estimations.

[2] A root crown is a large woody corm of a shrub from which numerous stems extend. In this region Alder (*Alnus crispa* and *Alnus rugosa*) and Beaked Hazelnut (*Corylus cornuta*) exhibited these post fire features.

The breakdown of accuracy by tree species (Figure 2.5) show that 74% of trembling aspen, 60% of balsam poplar, 56% of white spruce, 55% of black spruce and 59% of jack pine dominated stands were sampled were within the estimated error of the AVI decade of origin estimates. Figure 2.6 classifies the distribution of difference between the observed and A.V.I. estimated date of origin for all sampled stands as well as both trembling aspen and white spruce. All three distributions were demonstrated to be normal using Kolomogorv-Smirnov test of normalcy. Paired t-tests show the average overestimation of the A.V.I. of 9.4 years to be significant ($t=5.088$, $P<0.001$, $n=150$). The same paired t-tests of the A.V.I. age estimations and observed stand age of aspen dominated stands also did not show the average A.V.I. overestimation of 4.2 years to be significant ($t=1.533$, $P=0.131$, $n=54$). The same paired t-tests of white spruce dominated stands show the average overestimation of 12.5 years to be significant ($t=3.543$, $P=0.001$, $n=35$). The bias of all stands and white spruce dominated stands are within the expected margin (15 years from decade midpoint) of error of the A.V.I. date of origin estimates.

As the A.V.I. age difference increased there was an increasing probability that an edge was associated with a fire event. A logistic regression model of these probabilities (80.1% predictive) support this general observation (Fig. 2.2). As a reference for Fig. 2.4, the distribution of age juxtapositions of the study area is greatly skewed toward edges expressing a 0-10 year age juxtaposition (Fig. 2.3). The percent of the total edge delineated in the A.V.I. greatly decreases with increasing age difference. Drastic contrast of age class between stands seems to be the exception rather than the norm.

Of the 10,063km of AVI delineated forest edge[3], 38% occur in edges defined by a difference in dominant species alone and not a decade of origin

[3] The edges are identified as any change in decade-of-origin and/or dominant tree species as estimated and delineated within the Alberta Vegetation Inventory.

difference (Fig. 2.4). Overall, 72% of all the surveyed A.V.I. were associated with a detectable fire event. Sixty two percent of the edges had an estimated difference in decade-of-origin (Fig. 2.4). Of the remaining 6440km of edge, which did have an age difference, 72% had a probability of >69% that the edge was associated with a fire event. Thirty eight percent of all sampled edges were defined by an AVI difference in dominant species alone and not a decade of origin difference (see Fig. 2.2). These composition related edges had a only 20% probability that they represent a fire event.

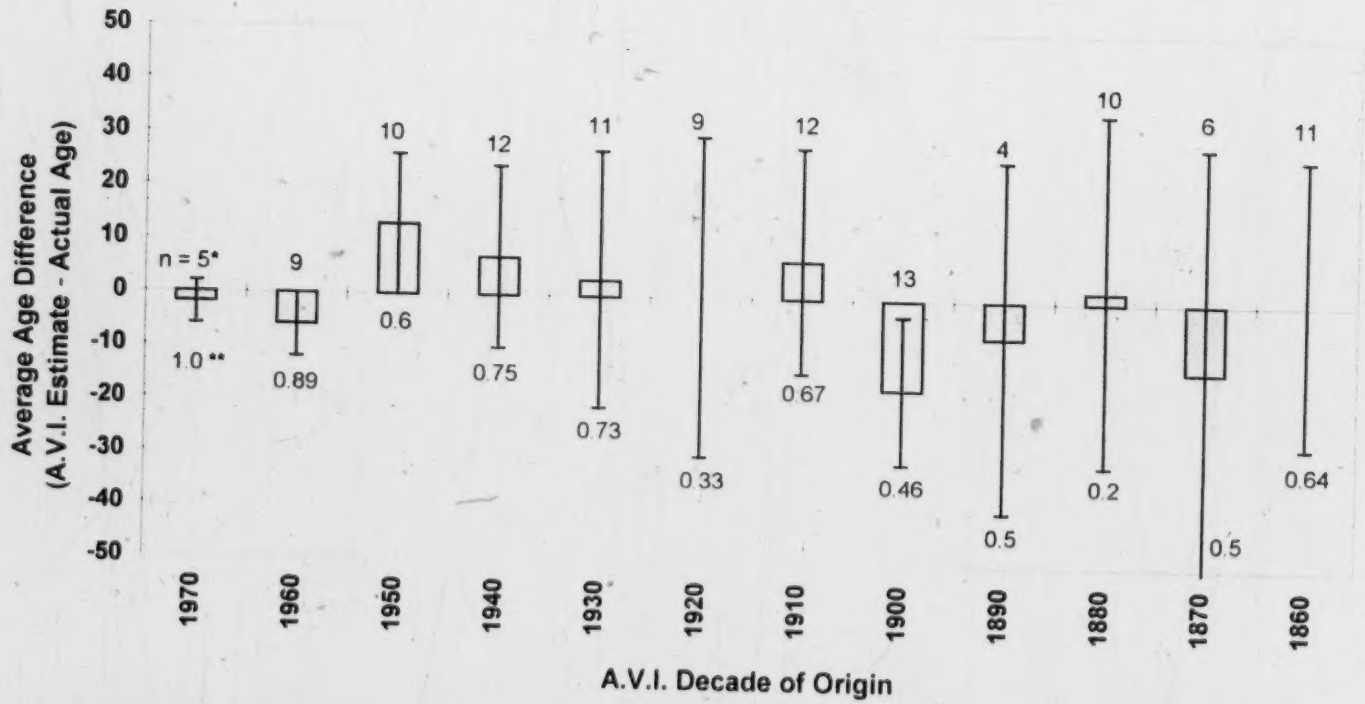



**Figure 2.2:** Average difference between the Alberta Vegetation Inventory (A.V.I.) estimations of stand origin and field observations (n = 112 stands, 3 cores/stand) with standard deviation. Estimated A.V.I. error is 10yrs. Poplar, spruce, pine and larch dominated stands are combined within this data. *number of stands sampled per age class. ** proportion of sampled stands within decade-of-origin class which were within ten years of A.V.I. decade-of-origin estimate.

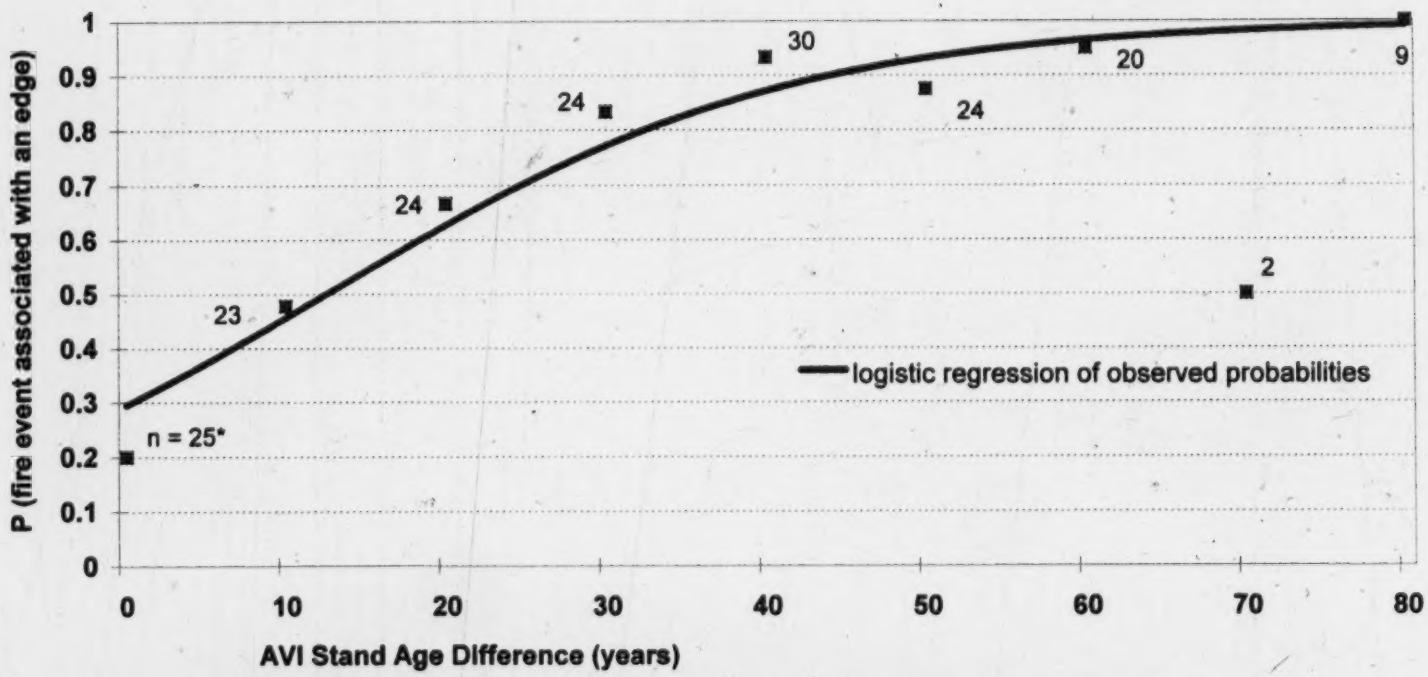



**Figure 2.3:** Logistic regression and observed probabilities (point data) that a past event fire can be predicted using the boundaries between decade-of-origin classes from the Alberta Vegetation Inventory.
n = 181, Correct predictions = 80.1%. *number of edges sampled per age juxtaposition.

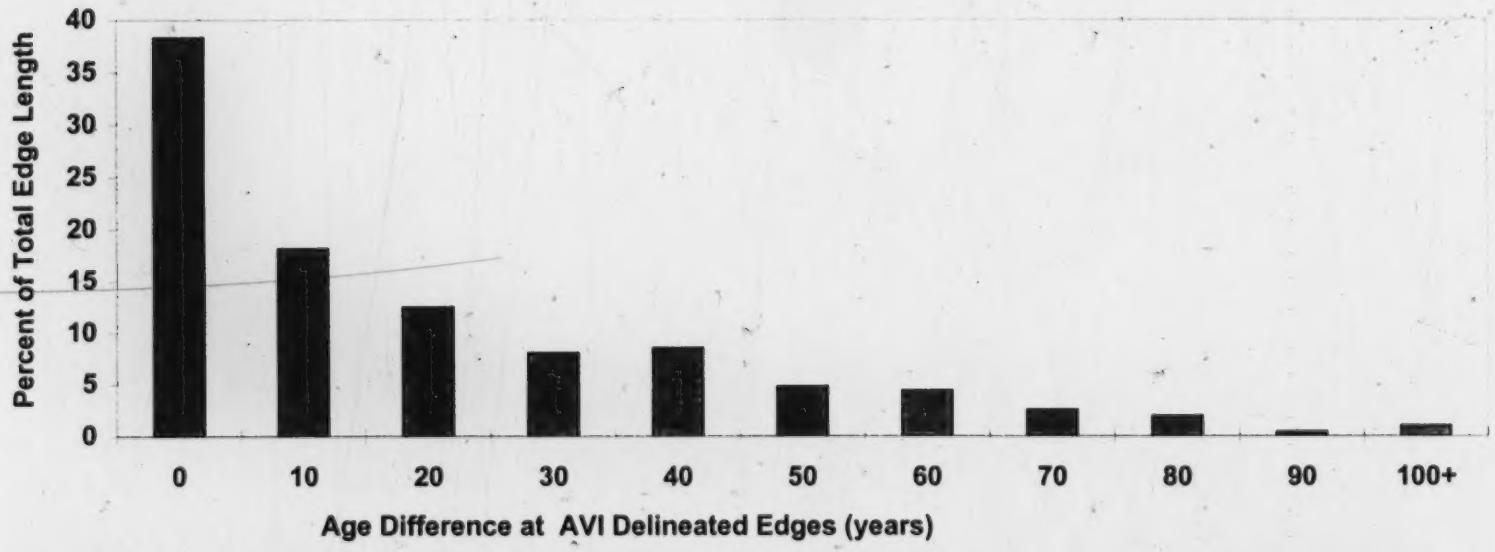



**Figure 2.4:** The distribution of age-class differences at forested edges as classified in the Alberta Vegetation Inventory. The distribution of age juxtapositions across the study area near Calling Lake, Alberta, is strongly skewed toward little age difference between adjacent forest stands. A age difference of 0 years indicates a difference in stand composition only. Total area=82,189ha. Total edge=10,063km. Internal forest had 133m edge/ha.

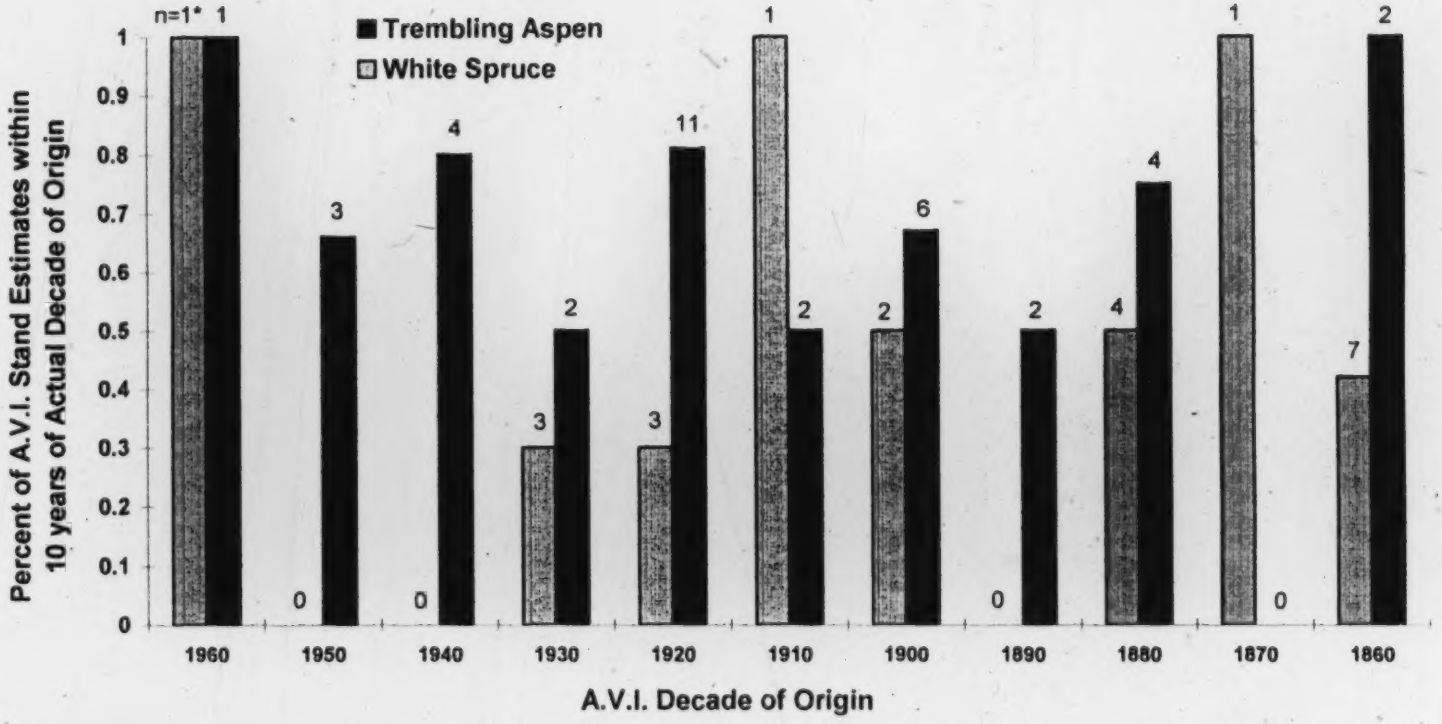
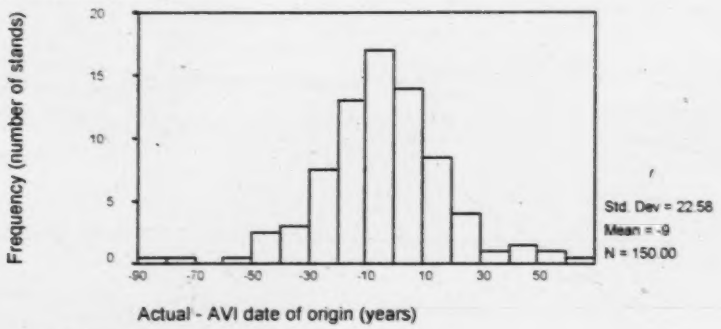
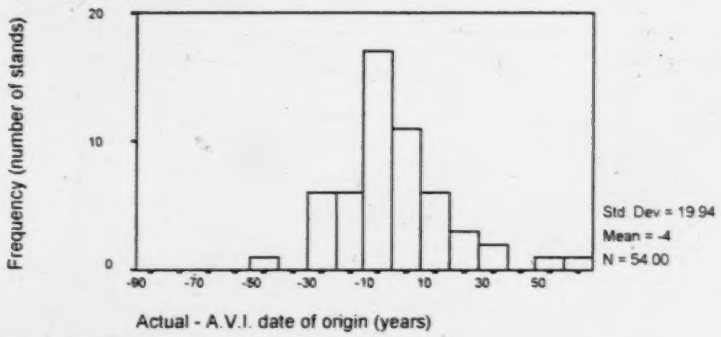



**Figure 2.6:** The percent of sampled stands dominated by trembling aspen and white spruce which had accurate decade of origin estimates (within 10 years of actual decade of origin) per AVI decade of origin estimate. *number of sampled stands within classification.

*(A)* **All Tree Species**




*(B)* **Trembling Aspen**




*(C)* **White Spruce**

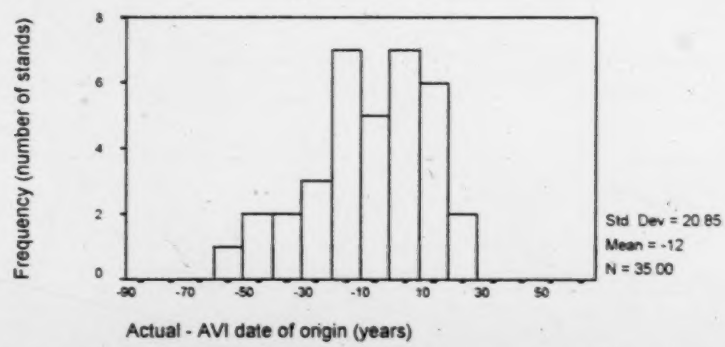



**Figure 2.6:** The distribution of differences between the actual and A.V.I. estimates of date of stand origin for stands dominated by all species (A), trembling aspen (B) and white spruce (C). Midpoints of the estimated decade of origin were used to estimate AVI error. Paired t-tests between the actual and AVI estimated age of the overall and white spruce dominant stands showed the average overestimation to be significant (respectively $P<0.001$, $t=5.088$, $n=150$ and $P=0.001$, $t=3.543$, $n=35$). The average overestimation within the aspen dominated stands was not significant ($P=0.131$, $t=3.543$, $n=35$).

## 2.6 Discussion and Conclusions

Across large areas (~10x10km), forest patches apparent in aerial photographs of the boreal mixed-wood forest of northern Alberta create landscapes of canopy age and composition that are relatively easy to assess. Boreal wildfires tend to be stand replacing, and occur at relatively high frequencies (Johnson 1992). This study shows that A.V.I. information produced from aerial photography to quantify the spatial patterns of stand attributes do express a reliable spatial record of past fire events. The general bias of the A.V.I. decade of origin estimations and that for white spruce are within the expected A.V.I. error. Such a bias were not considered to significantly affect the subsequent findings in this thesis.

A possible explanation for the increased deviation with stand decade of origin (Fig. 2.2) is the inadequacy of representative tree coring to represent the true age of older stands. Stands within the oldest age-classes (>120 years) tend to have multi-layered canopies making it difficult to identify trees which represent the date of origin or time-since-fire. Also there is a reported tree senescence of 120-180 years in boreal regions which biases the actual time since fire of older age classes (Fox 1989, Finney 1995). Other sources of A.V.I. error are the possible misinterpretation between white and black spruce stands, differential post-fire regeneration lags between species and sites types, and differential growth rates within stands dominated by the same tree species.

The A.V.I. decade of origin estimates are not an exact temporal record of fire events. However, if the primary concern is the spatial distribution of relative age classes rather than exact temporal record of fire events, the AVI can be used as a time-since-fire mosaic across broad landscapes. In short, the AVI coverage of the study area is a better spatial representation of the time-since-fire mosaic than it is an exact temporal record of fire events.

When mindful of the potential sources of error and constraints of temporal resolution, the observed likelihood of an age juxtaposition representing a past fire event is reliable. Additionally, a focus on the age distributions across landscapes, ignoring tree species composition, greatly simplifies the spatial pattern observed. It should be noted that reliability is scale-dependent in that error of large scale inventories becomes more problematic with smaller extents of observation. Studies focusing on areas less than ≈93km$^2$ (one township) should ground-truth the A.V.I. decade of origin estimates. The age-class distribution is a reliable representation of the region's fire history and can be used as a relative time-since-fire map over large extents of mixedwood boreal landscapes in Alberta.

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# CHAPTER 3

## *Are riparian forests unique within Aspen dominated Western Boreal Mixedwood landscapes?*

### *3.1 Introduction*

Riparian forests, those forest types generally found adjacent to standing or flowing bodies of water, have long been a concern of resource managers (Décamps *et al.* 1990). Historically, such concerns focussed on the prevention of erosion and water quality problems created by human activities and usually ended with a site-specific decision (Mander *et al.* 1995). In western boreal mixedwood regions of Alberta, these forested "zones" have been estimated to account for ~4.4% of the forested land-base (Cumming and Pelletier 1995).

Generally, riparian forests exhibit sharp ecotonal gradients of physical characteristics, plant communities, and ecological processes. Riparian zones can be described as water-land interfaces or as links between the aquatic and terrestrial systems. As such, they are considered essential for the long-term stability of aquatic systems and are a key component of landscape's inherent drainage and flood regulation (Gregory *et al.* 1991). In addition, they tend to retain woody and non-woody debris and serve to buffer exchange rates of dissolved/suspended solids between terrestrial and aquatic systems (Décamps *et al.* 1990, Vought *et al.* 1994). At regional scales of observation, the protection of entire watersheds becomes a concern as cumulative impacts of human activities may become apparent (Northern Rivers Basin Study 1996).

In terms of their role within the landscape, riparian forests can be viewed as linear resources and dispersal routes for plants, animals and materials

throughout a landscape (Gregory *et al.* 1991). Riparian corridors are believed to harbour an array of species and environmental processes that are more diverse than the surrounding landscape (Wood and Wood 1989). Variable flood regimes, geomorphic processes, micro-climate gradients, retrograde succession, upland influences, and complex biogeochemical cycles enable these regions to support a wide variety of ecological niches (Naiman *et al.* 1993, Kupfer and Malanson 1993). Indeed, boreal riparian forests contain important habitat of neotropical migrant avifauna and to enhance their local movement (LaRue *et al.* 1994, Machtans *et al.* 1995). Further, it has been reported that the 1% of western North America's landbase that riparian regions cover provide habitat for more bird species than the rest of the landscape combined (Knopf *et al.* 1988).

The frequency and intensity of wildfire events is considered to be lower in riparian zones (see Swanson *et al.* 1988). Because open bodies of water tend to act as fire breaks, it is probable that older forest stands would be associated with them. Boreal riparian regions of northwestern Ontario were shown to experience lower intensities of fire disturbance as well as exhibit higher species and structural diversity (Suffling *et al.* 1982). Using a broader extent and coarse resolution of observation, Cumming and Pelletier (1995) found no relation between the proportional area of riparian forest of a region and the area burned by wildfires caused by lightning. However, they did find fire occurrence to be positively associated with the area covered by conifer stands. In contrast, the broad, braided riparian areas of northern boreal systems experience extremely low rates of fire disturbance, differ from the surrounding region in terms of forest in forest productivity, species composition and harbour the tallest white spruce stands (≈45m) in the world (Timoney and Robinson 1996, Timoney and Peterson 1996).

The tendency to associate increased biodiversity, retarded disturbance regimes, and increased structural diversity with riparian regions across all scales

and regions, may be a misleading extrapolation from location-specific studies. Therefore, the perceived "uniqueness" of riparian forests in the western boreal mixedwood of Alberta may not be consistent at broader extents and a coarser resolution of observation.

With a widening extent of observation, there is usually an increase in the variation of topographic attributes (Sayles and Thomas 1978, Thomas *et al.* 1979) and physical and biological factors (Bell *et al.* 1993.). Further, it has been suggested that landform (the specific topography and geology of a region) is the dominant influence on spatio-temporal hydrologic/disturbance regimes of a landscape (Forman and Gordon 1986, Swanson *et al.* 1988). These possibilities seem to reduce the relevance of a somewhat over-generalized correspondence between adjacency-to-open-water and the structural diversity within boreal landscapes.

Few studies have examined broad scale trends in vegetation diversity associated with riparian areas and/or landform effects. Landform effect was considered the prominent influence on forest composition in the study by Ericsson and Schimpf (1986) who found that the riparian forests of a southern-shore tributary of Lake Superior were not considerably distinct from the surrounding landscape. Also, Baker's (1990) regional scale study of macro-topographic influence on plant species of the western Colorado rockies found no trend of overall species richness with elevation or topographic orientation. In the forested region surrounding my study area, Cumming and Pelletier (1995) commented on crude landform effects as they discussed the higher proportion of white spruce (*Picea glauca*) dominated regions around the major course of the Athabasca River. However, ecosystems contained within the floodplains of larger rivers do tend to differ from surrounding forest communities (Timoney and Robinson 1995). Clearly, the discussion of landform effect on both disturbance regimes and vegetation communities is location and scale-dependent.

Considering the relatively mild topographic relief of boreal regions, as well as the numerous wetland regions. I asked the following questions: how different are forests adjacent to open bodies of water when compared to the surrounding landscape? Is it ecologically appropriate to consider that unharvested riparian buffer-strips serve as incidental reserves of regional and/or landscape biodiversity for vegetation communities? Is a reduced fire intensity/frequency and increased vegetative diversity of riparian regions a consistent property at a landscape scale? The focus of this chapter is to address these questions at a scale relevant to harvest planning and operations by examining forests adjacent to moderately sized lakes.

### *3.2 Objectives*

The main objective of this project was to determine whether forested riparian regions have consistent characteristics across the mixedwood boreal landscape. In terms of the time-since-fire distribution and the dominant tree species I compared the percent cover of trembling aspen and white spruce and the cover of young (60-70 year old) and old (120-140 year old) stands of riparian forests and the surrounding landscape. This comparison was intended to define the difference between local riparian and upland forest composition attributes. Specifically, I explored the degree to which forested regions adjacent to small and mid-size open bodies of water are different from local forested regions (i.e. local uplands) barring extensive peatlands.

### *3.3 Study Area*

As in Chapter Two, two regions were used in this survey; one south of Calling Lake and the other north of Lac La Biche, Alberta. Together they consist of 11 townships[1] (~93km$^2$/TWP) and include ~82,000ha of forested land. These

[1] Townships included in the survey conducted for this chapter include T70-R11, T71-R11, T71-R12, T71-R13 and T72-R11, north of Lac La Biche, Alberta, and T70-R25, T71-R24, T71-R25, T72-R24, T72-R25 and T73-R24 south of Calling Lake, Alberta.

areas are the regions which had complete A.V.I. coverage and are under study by the TROLS project. Additional areas adjacent to the study area, and with full A.V.I. coverage, were included to provide a larger land-base for inquiry. Both regions are typical of southern boreal mixed-wood landscapes that include; trembling aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), white spruce (*Picea glauca*), black spruce (*Picea mariana*), tamarack (*Larix laricina*), paper birch (*Betula papyrifera*), jack pine (*Pinus banksiana*) and balsam fir (*Abies balsamea*). All forested areas given an A.V.I. estimate of decade of origin were considered in the survey.

### *3.4 Methods*

Twelve lakes, with areas between 5 and 100 ha, were chosen. These lakes were the only small to mid-sized lakes in the study area for which digital information was available. Large lakes, rivers, bogs and fens with open water were avoided. The data set was generated within the Spatial Information Systems Laboratory, Department of Renewable Resources, University of Alberta.

For comparison to the forest cover around the sample lakes I created simulated lakes and placed them in the surrounding landscape. An exact duplicate of each of the twelve study lakes was generated and artificially re-located within the township (10km x 10km) that it occurred in. This process simply changed the archived co-ordinates of each lake to create an exact copy in another area. When locating the simulated lakes, they were placed in the nearest local "upland" with a minimum of 2km distance between the simulated lakes and the "original" lakes, other "simulated" lakes, extensive peatlands, extensive wetlands and other open bodies of water. These locations were identified using 1:50,000 NTS maps.

For each lake and simulated lake, twelve buffers of increasing width were generated at 50m intervals up to 600m using the *r.buffer* GRASS commands. Simple *r.reports* were then generated for each buffered area to create the proportional area covered for each forest attribute. These twelve buffer widths were used to define the buffer width at which differences and/or trends emerge.

A.V.I. stand polygons define canopy composition by estimating the percentage (to the nearest 10%) of up to three tree species present in the stand. In this study, each polygon was reclassified to represent only the most abundant species that occurred within the stand boundaries. Stands that were dominated by trembling aspen and white spruce were used to assess forest composition while age classes of 60-70yrs and 120-140yrs represented the relative time-since-fire. These two classes represent the dominant time-since-fire classes of the entire study area (see Chapter 4). This may seem a crude classification but was used because the estimates of other tree species are suspect as species such as balsam fir, balsam poplar and white birch are often under-estimated in the A.V.I. The cumulative percent cover of each class was calculated per buffer width.

Paired t-tests comparing the four canopy attributes within each buffer width of each pair of real and simulated lakes were conducted. The null hypothesis is that there were no differences between riparian and local upland regions.

This scale of observation was used because buffer-strips are designed on a lake-by-lake basis. Conceptually, looking from the middle of a lake out, this approach underlies the common method applied to riparian forest regions and buffer-strips. Hence, any broader scale "landform" influences (e.g. surface geology, exposure, slope) affecting the composition of riparian regions are not acknowledged.

### *3.5 Results*

There was high variance in the average percent cover for all attributes (see Fig. 3.1 & 3.2). The percent cover of trembling aspen in the buffers around real lakes increased with greater buffer widths from 35% to 51.2%. There was a slight decrease in trembling aspen cover around simulated lakes from 49.1% to 41.3% with widening buffers. White spruce cover increased around real lakes from 7.5% to 11% with wider buffers. A slight decrease in white spruce (13% to 11.5) was associated with widening buffers around simulated lakes. None of these trends were statistically significant.

For the real lakes the percent cover of the 60-70 years-since-fire class slightly decreased with widening buffers from 5.2% to 2.6%. The percent cover of the same class decreased from 8.1% to 0.9% with widening buffers around simulated lakes. The percent cover of the 120-140 years-since-fire class also decreased slightly with widening buffers and ranged from 7.4% to 9.5%. However, there was an increase from 10.2% to 14.8% in the percent area covered by the 120-140 years-since-fire class around simulated lakes.

The maximum difference between averages for the real and simulated lakes was 14%. However, when considering the variance, this cannot be considered biologically significant. There was extreme variance within all attributes and buffer widths. Therefore, any subtle trends or differences are misleading.

Paired t-tests comparing the percent cover between the sets of real and simulated lakes showed significant difference between the riparian and local upland sites for three of the forty-eight comparisons (Table 3.1). All other t values were less than $t_{0.5(2),11}$=0.7. Therefore the null hypothesis was accepted.

**Table 3.1:** T-values for the pair wise t-tests comparing the difference between the pairs of real and simulated lakes. Three of the above comparisons (*) merit a rejection of the null hypothesis ($t_{12*0.5}$=0.7) that there is no consistent difference between the percent cover of the canopy composition and forest age around real and simulated lakes.

| Buffer Width (m) | Trembling Aspen | White Spruce | 120-140 y.s.f. | 60-70 y.s.f. |
|---|---|---|---|---|
| 50 | 0.267 | 0.282 | 0.199 | 0.682 |
| 100 | 0.289 | 0.248 | 0.413 | 0.751* |
| 150 | 0.322 | 0.318 | 0.572 | 0.578 |
| 200 | 0.471 | 0.576 | 0.531 | 0.674 |
| 250 | 0.438 | 0.534 | 0.417 | 0.631 |
| 300 | 0.562 | 0.713* | 0.473 | 0.721* |
| 350 | 0.631 | 0.621 | 0.512 | 0.646 |
| 400 | 0.517 | 0.680 | 0.583 | 0.656 |
| 450 | 0.482 | 0.566 | 0.601 | 0.583 |
| 500 | 0.526 | 0.387 | 0.558 | 0.646 |
| 550 | 0.387 | 0.311 | 0.467 | 0.603 |
| 600 | 0.298 | 0.241 | 0.358 | 0.661 |

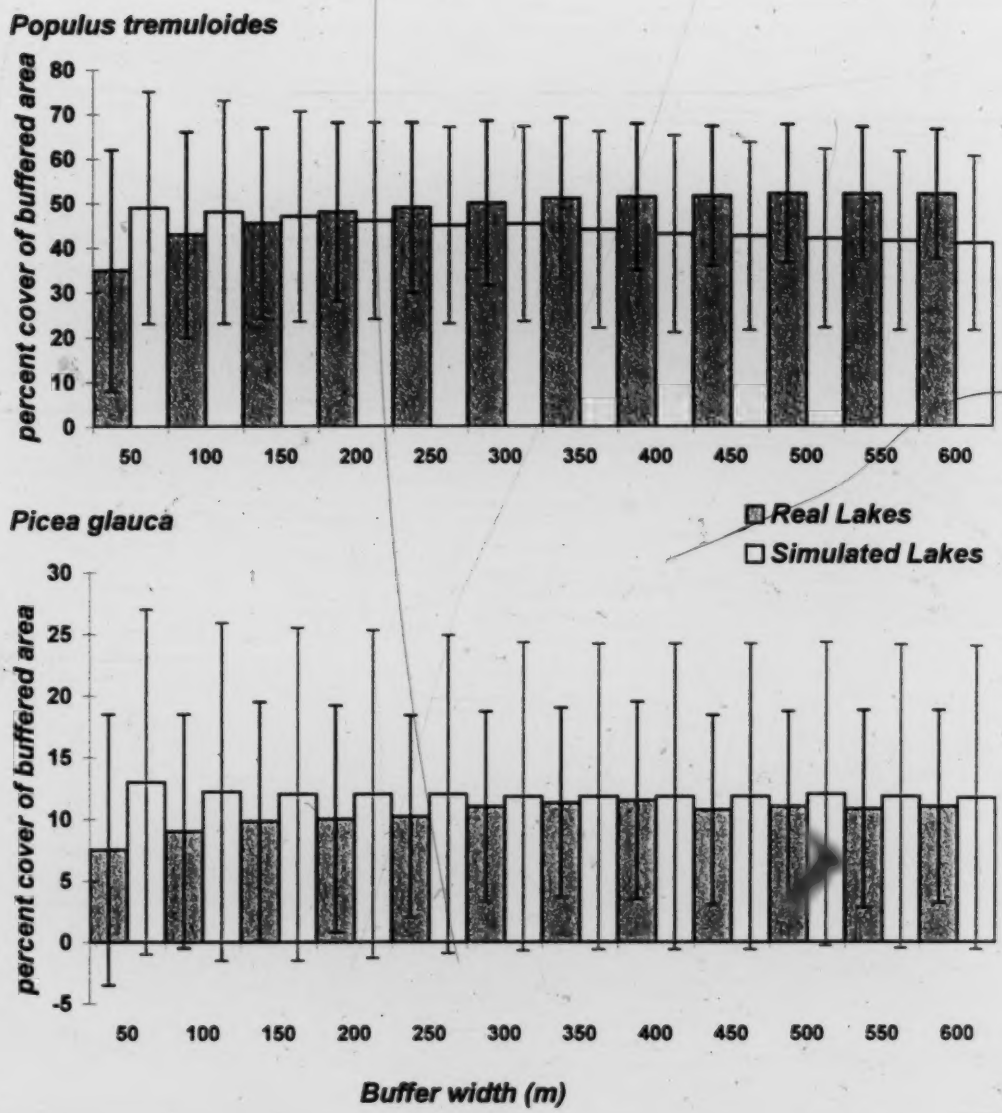


***Figure 3.1:*** Average cumulative percent cover and standard deviation of *Populus tremuloides* (n = 12) and *Picea glauca* (n = 12), with increasing buffer width, around real and simulated lakes ranging from 5 - 100ha. These species represent the two dominant tree species present within the study area.

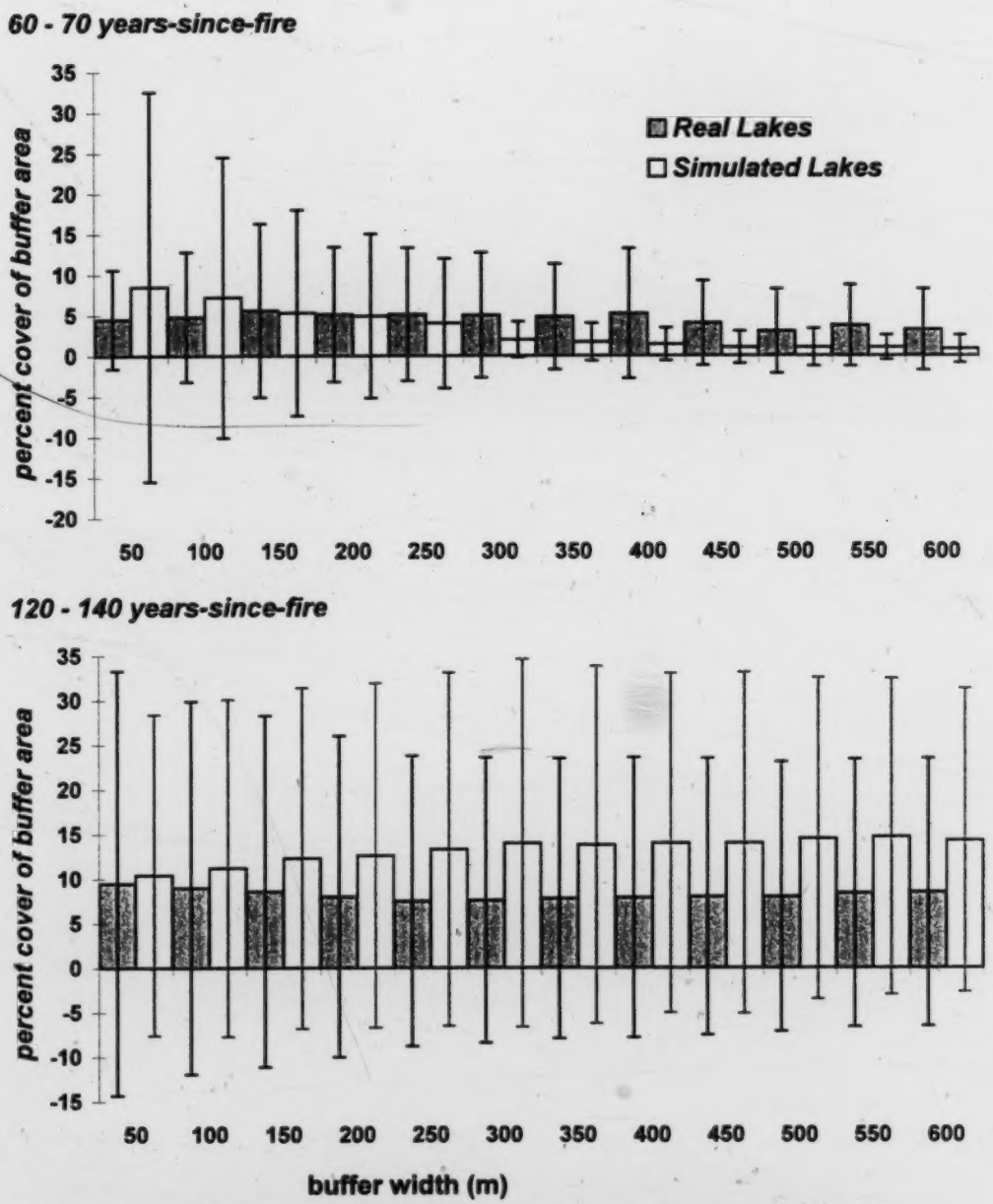


***Figure 3.2:*** Average cumulative percent cover and standard deviation of forest cover 120-140 (n = 12) and 60 - 70 (n = 12) years old around real and simulated lakes with increasing buffer width. These time periods cover the two dominant fire episodes apparent in the region's wildfire history (see Chapter 4 for fire history).

### *3.6 Discussion and Conclusions*

Canopy species composition and time-since-fire of forested regions (barring peatlands) adjacent to small or mid-size lakes did not appear to be consistently different from the surrounding forested landscape. However, this lack of difference is specific to the extent and resolution of the data employed in my study.

These are consistent with some other studies (see Ericsson and Schimpf 1986, Cumming and Pelletier 1995). Finer scale studies (Suffling *et al.* 1982) have shown an increased number of old trees adjacent to lakes in boreal mixedwood forests. Due to the resolution of the A.V.I. data (0.4ha), the forested areas within 50m of lake edge were not examined at finer resolutions.

Lakes occur at various elevations and are associated with a variety geologic and glacio-fluvial settings throughout this landscape. Therefore, the surrounding forest pattern may be the result of mechanisms which become apparent with broader extents of observation. If this is the case, observing a small strip around the lakes and simulated lakes may be insufficient to detect larger scale patterns. Further, adjacency to water-bodies may not correlate with landscape features that support structurally unique forest attributes. It is possible that lakes are nested within forest patterns which occur at larger scales. Chapter 4 discusses this in more detail.

The forested systems around the lakes and simulated lakes may be nested within broader landscape/landform influences. Therefore, utilizing riparian zones around moderately sized lakes, as a substitute for landscape reserve design, will not ensure the overall conservation of unique forest canopy attributes. Still, smaller scale patterns and processes may be more important for riparian biodiversity. The riparian forests around rivers and tributaries may have larger regions of influence and therefore this aspect needs to be examined separately. My findings should not be extrapolated to other drainage types or

ecoregions. Noting the broad scale of this inquiry, watercourse protection and the use patterns of fauna are more appropriate foci of riparian forest management around small to mid-sized lakes in the western boreal mixedwood than as incidental reserves of unique forest types.

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# CHAPTER 4

## *Forested Landscape Patterns in the Western Boreal Mixedwood: combining patterns of topography, time-since-fire and dominant tree species to infer mechanisms of long term wildfire behaviour and tree species distribution*

### *4.1 Introduction*

Topographic orientation (or landform), as described by combinations of elevation, slope, aspect, and relief texture, has been suggested and shown to have an influence on the fire history and behaviour of wildfires across forested landscapes in North America (Heinselman 1973, Rowe and Scotter 1973, Tande 1979, Suffling *et al.* 1988, Swanson *et al.* 1988, Bergeron 1991, Johnson 1992, Turner and Romme 1994, Velben *et al.* 1994, Francis 1996, Rogeau 1996). The probable mechanism for this influence is that classifications of topography serve as indirect, but spatially consistent, estimates of micro-climate, surface and near-surface moisture, and timing of spring thaw (see Whittaker 1953, Pennock *et al.* 1987, Hall and Olsen 1991). There is a tendency for the topographic structure of a region to create static patterns of drainage. These patterns are the result of interplay between water-driven erosion and the geologic structure of a landscape, that determine relative moisture and micro-climate patterns.

The prevailing models of fire regimes (Van Wagner 1978, Johnson and Van Wagner 1985, Johnson and Gutsell 1994) which calculate different parameters of a region's fire cycle assume that fire disturbances are spatially random. Generally, these models fit cumulative time-since-fire distributions to

negative exponential or Wiebull probability distributions which are then used to estimate various fire regime parameters such as fire return interval and annual area burned. It follows that, assuming fire occurrence is spatially random, the proportional distribution of areas covered by the cumulative time-since-fire class of a landscape is indicative of temporal variation in weather conditions.

Fire is the dominant disturbance in the boreal forest with an estimated 5% of the severe wildfires contributing about 90% of the burnt area per unit of time (see White 1995, Johnson and Wowchuck 1993 for sub-alpine examples). These estimates are derived by examining large landscapes.

The influence of landform on fire behaviour and history has been observed in mountainous regions of North America (Swanson *et al.* 1988, Turner and Romme 1994, Francis 1996, Rogeau 1996) but has not been explored for western boreal mixedwood regions. It is not intuitive that the usually mild relief of boreal regions may influence forest landscape patterns. Suffling *et al.* (1988) observed that wildfire trends induced by climate were complicated by relatively dry geomorphological features that had increased numbers of fire occurrences. However, rigorous examinations of large tracts of forest have only recently become possible, with the increasing availability of detailed digital information.

Although the influence of topography on wildfire history has been demonstrated by other studies in North America it is assumed not to play an important role in boreal landscapes. These apparent contradictions result from a lack of appreciation of the full variability of spatio-temporal conditions (Turner and Romme 1994, Francis 1996). For example, the dry extreme of climatic variation greatly reduces the landform influence on fire behaviour. Alternatively, wet conditions can render the same fuel types incombustible. Most likely, it is during intermediate conditions, when a landform influence could have the greatest effect on wildfire behaviour. These contradictory interpretations of the

influence of topography may be the result of different scales of observation supporting different and contradictory interpretations of emergent properties observed for the same systems (see Allen and Hoekstra 1987, Addicott *et al.* 1987, Meentenmeyer and Box 1987, Shugart and Urban 1988, Turner *et al.* 1989, Norton and Lord 1990, Wiens 1990, Holling 1992, Miguel *et al.* 1995, Holling and Meffe 1996).

This contradiction may become critical when addressed within a forest management context. The majority of harvest planning is conducted using smaller landscapes with shorter time horizons than most fire history studies. Resource planning efforts that attempt to maintain the ecological integrity of a region or ecosystems require accurate information applicable to specific issues. The assumption that fire occurrences and/or frequency are spatially random must be tested at scales in which people actually operate and plan on before it can be relied upon.

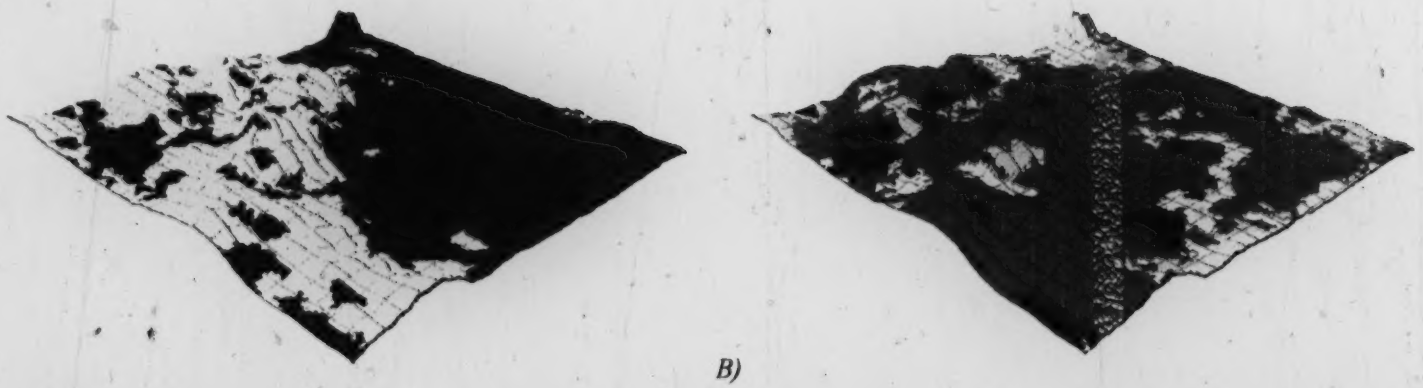
Images created in the GRASS (Anon. 1993) G.I.S. computing environment (Fig. 4.1), with digital coverages within the study area, suggested anecdotally a relationship between landscape relief and time-since-fire as well as landscape relief and patterns of tree species. The pattern of trees across a landscape is expected to correspond to landform orientation (Kimmins 1987). However, this visual association between time-since-fire and topographic orientation seemed contrary to conventional thought on the subject. Convention assumes that there is little relationship between topography and the fire history of boreal landscapes (see Johnson and Gutsell 1994). These contradictions required further inquiry.

The fuel complex of a boreal landscape, which can be classified using canopy characteristics, has also been shown to influence the rate of fire spread (Alexander *et al.* 1984), as well as fire history and behaviour (Chandler *et al.*

1983). Using a very large study landscape, Cumming and Pelletier (1995) found the number of lightning caused fires to be closely associated with the dominant tree species rather than proximity to open water bodies in the western boreal mixedwood. Assessments of fire hazard consistently include the differential rate of wildfire spread in different fuel conditions (Chandler *et al.* 1983, Forestry Canada 1992, McRae 1996). Although rates of fire spread are primarily related to the behaviour of a specific fire event once ignited, it is a logical extension to infer that it also represents a differential ignition potential given equal fine fuel moisture conditions.

Dix and Swan (1970) considered all tree species that occur in western boreal mixedwood forests, except balsam fir (*Abies balsamea*), to be post-disturbance pioneers whose spatial distribution is largely determined by site conditions. Dominant post-fire canopy patterns are a result of interaction of variables such as pre-fire composition, edaphic moisture and texture, seed bed, and seed crop years (Dix and Swan 1970, Suffling *et al.* 1988, Galipeau *et al.* 1997). For years it has been suggested that the climax concept, or directional succession, is "unreal" and "unjustified" (Dix and Swan 1970) for this region and should not be used in forest resource planning. Still, adherence to these concepts remains widespread today.

This study analyzes the organizational patterns of boreal mixedwood landscapes using the information relied upon by, and at a spatial scale relevant to, forest resource planning and harvest operations and forecasting. By focusing on a specific landscape in the western boreal mixedwood of Alberta, this study addresses the influence of landform on forest age (long-term fire behaviour and frequency) and canopy composition. By assessing this influence in a spatio-temporal context, this study is a contribution of appropriate information with which to evaluate the natural disturbance model of forest resource harvest in Alberta.



A) B)

**Figure 4.1:** A 3-D perspective of a dominant tree species map (A) and time since fire map (B). Dominant tree species of Map A include: *Populus tremuloides* - yellow, *Populus balsamifera* - green, *Pinus banksiana* - blue, *Abies balsamea* - red. The decade-of-origin classes range through a colour gradient from 1860 - green, through to 1960 - red. The black regions of both landscapes are non-forested; predominantly lakes and wetlands. The southwest corner is in the forefront. This coverage is of the ~4.5 x 4.5km region with UTM boundaries N-611962, S-6107312, E-445537, W-447037, North of Lac La Biche, Alberta. Elevation is exaggerated by a factor of 1.5 and ranges 574 - 664 m.a.s.l..

### *4.2 Objectives*

The objectives were to:

*1)* describe relationships between landform (as measured by topographic orientation), time-since-fire, and dominant tree species,

*2)* evaluate the assumption of spatially random fire occurrence at a scale relevant to resource planning efforts, and

*3)* examine possible associations between the pattern of lightning strikes, topographic orientation, the present distribution of dominant tree species and the time-since-fire mosaic.

### *4.3 Study Area*

The study area was a continuous region of mixedwood boreal forest near Calling Lake, Alberta (UTM N-6153987m, S-6098987m, E-358012m, W-318012m, Fig. 4.2). A composite map of the study area was created in a GRASS G.I.S. (Anon. 1993) environment using the digital inventories of nine townships, covering about 60,000ha of forested land and with complete pre-harvest forest cover recorded in the Alberta Vegetation Inventory (1995) format. These data have a minimum stand resolution of 0.4ha (Joy 1995). All forested areas given an A.V.I. estimate of decade-of-origin and stand composition were considered in this study.

The region is typical of southern boreal mixedwood landscapes and include tree species such as trembling aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), white spruce (*Picea glauca*), black spruce (*Picea mariana*), tamarack (*Larix laricina*), paper birch (*Betula papyrifera*), jack pine (*Pinus banksiana*) and balsam fir (*Abies balsamea*).

### *4.4 Base Data and Digital Landscapes*

The sampling and data sets used in this Chapter were all generated within a GRASS G.I.S. computing environment. All data were converted from an original format to be compatible with this system. Also, G.I.S. coverages were manipulated to create data layers to be used to measure the attribute(s) in question. The following is a description and images of the various classifications and data layers that were used in this chapter.

The first generation of the A.V.I. digitally records continuously forested landscapes as a resource and harvest planning aid. For each identifiable stand on the forested land-base, including peatlands, numerous attributes are estimated including crown closure, height, tree species composition (up to three dominant tree species), stand structure, understory type, drainage class, and decade-of-origin. The A.V.I. information of the eleven townships in the study area were classified in age and dominant species data and a continuous coverage was made of the study area. Figure 4.3 is displays the A.V.I. dominant species and age data for the study area. Age classifications are based on height vs. age regressions, per species within the inventoried region. Species are classified using canopy signatures identifiable from aerial photographs.

Digital Elevation Models (D.E.M.s) were purchased from the Data Resources office of Environmental Protection Alberta. Basically, these D.E.M.s are continuous map-layers of elevation data which have been developed through digital interpolations, or surfacing algorithms, of baseline topographic maps. D.E.M.s of mapsheets 83p03, 83p04, 83p05, and 83p06 from the Alberta base-map topographic series were combined to form a continuous layer of elevation data. Accuracy of this data, at 20m resolution, is estimated by the developers to be within 15m of actual elevation due to the amount of smoothing required of the

algorithm. The elevation ranged 344m from 517m to 861m above sea level (m.a.s.l.) over the extent of the D.E.M. (Fig. 4.2).

The various D.E.M. and A.V.I. mapsheets were "pasted" together using the *r.patch* command to form separate composite maps expressing forest stand decade-of-origin, dominant tree species, and elevation to create continuous layers of data (Fig. 4.2 & 4.3). The decade-of-origin stand classifications and the dominant tree species present in the canopy were isolated from other forest attributes and archived as separate coverages. Knowing that the AVI decade-of-origin estimations for this region adequately represent fire history (see Chapter 1), the map expressing the decade-of-origin is hereafter referred to, and considered as, the time-since-fire mosaic for the region.

After creating these three coverages, the G.I.S. sampling landscape was defined with a data filter created using the *r.mask* command. This mask excluded any area for which there was no forest cover and was used to generate queries for analyses that required only the forested areas of the landscape.

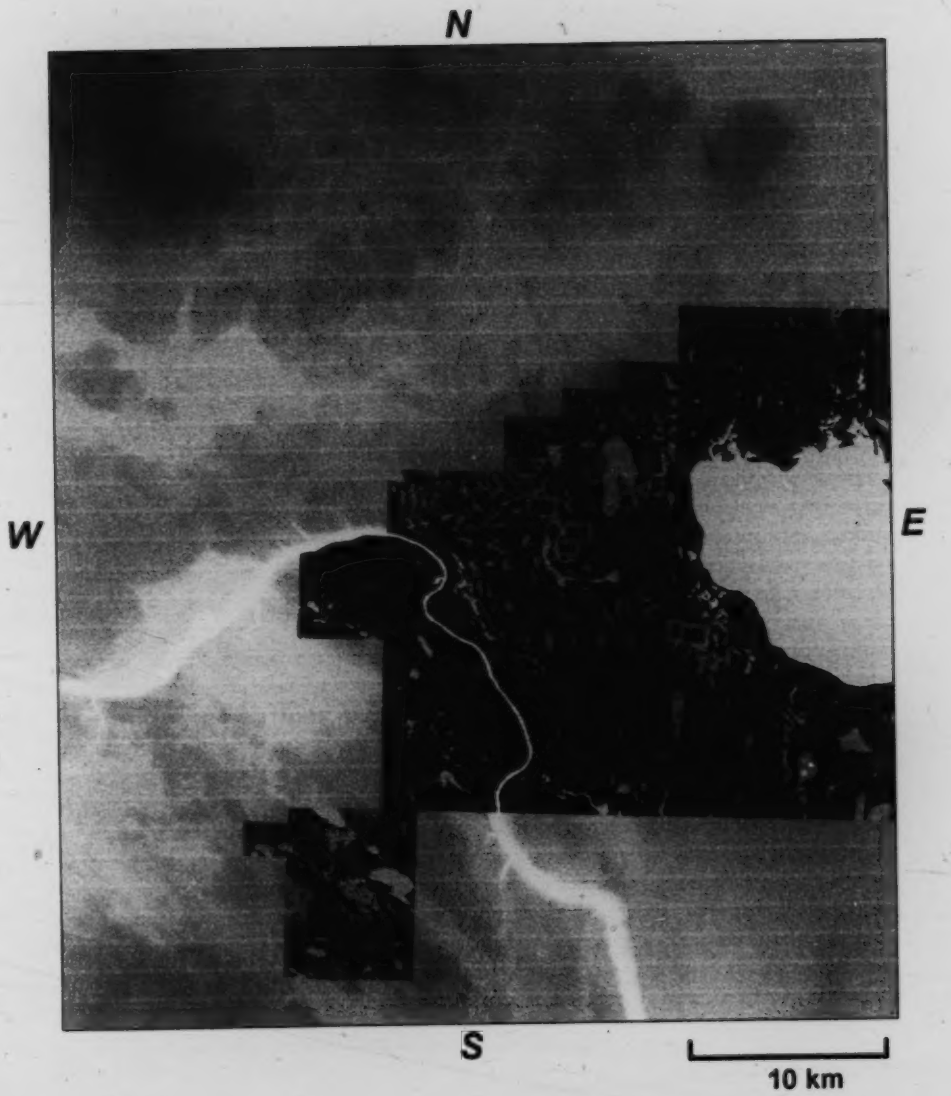



**Figure 4.2:** The region in black is the study area (~52,000ha) for which continuous forest cover data (Alberta Vegetation Inventory 1995) were available. The coloured region is the area covered by the digital elevation model used to generate the landform classifications (UTM N-6153987m, S-6098987m, E-358012m, W-318012m). The elevation ranges 344 m; from 517-861 m.a.s.l. and is coloured from low to high elevations as yellow through to red. The forested cover encompasses portions of Calling Lake and the Athabasca River, Alberta.

Using the D.E.M., separate mapsheets were created which represented attributes of topographic orientation including elevation above sea level (m.a.s.l.), localized elevation, specific exposure, and slope. The elevation ranged ~190m from 530-720 m.a.s.l. in the forested landbase of the study area. To generate measures of landform, combinations of attribute mapsheets (Fig. 4.4 & 4.5) were classed using *r.reclass, r.cross, r.patch, r.aspect, r.neighbor, mapcalc* and *r.slope* GRASS commands. The classifications of topographic orientation that were used were generated from the D.E.M. and include:

*Regional Elevation Change,*

***1)*** five classes of equal range in elevation (approx. 40m/class),

***2)*** ten classes of equal range in elevation (approx. 20m/class),

***3)*** three equal-area classes between the elevation ranges 529-635 m.a.s.l. (low 1/3) , 635-660 m.a.s.l. (mid 1/3), and 660-721 m.a.s.l. (high 1/3),

*Aspect of Exposure,*

***4)*** slope exposure classed into the four cardinal directions including north (315-360°, 0-44°), east (45-134°), south (135-225°), and west (226-315°),

***5)*** slope exposure classed into eight general directions including north (348-360°, 0-23°), north-east (24-78°), east (79-123°), south-east (124-168°), south (169-213°), south-west (214-258°), west (259-303°), and northwest (304-360°),

***6)*** slope exposure classed into all 360° of compass directions,

*Local Elevation,*

***7)*** local elevation that assigned the difference in meters between each raster cell and the average elevation of the area within a 500m radius of that cell,

*Slope Classes,*

***8)*** slope gradient classed into 37 classes, one for each degree of slope gradient, from 0 to 37° from horizontal, and

***9)*** crude slope gradient classed into two approximately equal areas with gradient 0-2° and >2°.

**Figure 4.3:** A visual comparison of the time-since-fire *(A)* and dominant tree species mosaic *(B)* of the study area (~52,000ha) near Calling Lake, Alberta. Map *A* is classified into decades and coloured in a gradient from the youngest (~5 y.s.f.) forest regions coloured red, through orange, yellow, to green which represents the oldest regions (~177 y.s.f.). Map *B* is classed by dominant tree species of forest stands and are coloured as: *Populus tremuloides* - yellow, *Picea glauca* - red, *Pinus banksiana* - dark blue, *Populus balsamifera* - light blue, *Betula papyifera* - green, *Picea mariana* - violet. The classifications are based on the Alberta Vegetation Inventory (1995) interpreted mainly from 1:15,000 large-format ortho-photos.

A) B) C)

**Figure 4.4:** Classifications of the digital elevation model for the forested region near Calling Lake Alberta. Map *A* represents the aspect of exposure with east facing sites black ,with a gray scale gradient through to the white, west facing sites. Map *B* displays the slope gradient with the coloured regions having a slope of >1°. Map *C* is a classification of Map *B* with slopes <2° coloured red and slopes >2° coloured gold.

**Figure 4.5:** Classifications of the digital elevation model of the forested study region near Calling Lake, Alberta. Map *A* expresses the three equal-area ranges of the region's elevation: low 1/3 - green, middle 1/3 - blue, high 1/3 - red. Map *B* displays the local elevation relative to the average elevation of the area within a 500m radius of each raster cell. The colour classification of Map B has been randomized for presentation and visually exaggerates variation. Map *C* shows the study region's elevation classed into 10 ranges of equal elevation range but unequal area.

### *4.5.0 Lightning Strikes*

Lightning has long been regarded as the primary source of ignition of wildfire (Kourtz 1967, Komarek 1968). Therefore, the pattern of lightning strikes across a landscape may differentially create ignition prone areas and result in differential wildfire frequency. Section 4.5 explores the potential for lightning patterns across the study area.

Also, the direction of a lightning strike event may correspond with differences in strike location and strength. Strikes in which the current travels from the ground to a cloud mass tend to be of a higher voltage, longer duration and occur away from the storm front (Smith *per comm.* 1996, Beaver *in prep.*). Therefore such strikes may have a higher probability of occurring on dry ground. This hypothesis has not been empirically tested for boreal regions (Smith, Meteorologist, Alberta Environmental Protection, per. comm. 1996) but the potential for such a difference was incorporated into my analyses.

#### *4.5.1 Testing For Lightning Prone Areas*

Lightning strike data were obtained courtesy of the Fire Weather Centre, Alberta Environmental Protection. These data consisted of the 7,953 lightning strikes which were recorded in the study area from 1992 to 1995. The UTM coordinates, direction (cloud-to-ground or ground-to-cloud), and the relative intensity were recorded for each strike. Strike events were collected using a VHT tower system (see Oetzel 1969, Global Atmospherics 1996) and are estimated to be accurate within 3km (Smith *per. comm.* 1996).

The *s.menu* suite of GRASS commands were used to interface site locations with other data layers and combinations thereof in order to explore the potential for spatial clustering of strike locations. Chi-square ($x^2$) goodness-of-fit statistics were produced for the lightning strike locations for each of the nine classifications of topographic orientation. This exercise measured the number of

expected sites (assuming random distribution) based on area cover per raster class, against actual site occurrence. Statistics were produced for strikes within each of the 9 topographic classifications, the following topographic class combinations (described above in section 4.4): 1+4, 1+5, 1+7, 1+9, 3+4, 3+5, 3+7, 3+9, 4+7, 4+9, 5+7 and 5+9, the present time-since-fire mosaic, the present dominant tree species mosaic, as well as the combination of time-since-fire and dominant tree species.

### *4.5.2 Results*

The pattern of lightning strikes in the study area does not deviate from random distribution across the forested landscape (n=7,953, $\alpha$=0.05). Lightning strikes randomly hit the landscape as classified of the D.E.M., as well as that of the age and species forest cover classifications.

### *4.5.3 Conclusion of Lightning Patterns*

This demonstrates that lightning strikes did not deviate from a random pattern. Therefore, all points of the landscape have the same probability of experiencing a strike event per unit time. However, McRae (1992) did find local topography to be predictive of strike occurrence while Kourtz (1967), found a majority of strike locations in high elevation classifications. Such tendencies cannot be completely discounted for the study region because of the relatively crude resolution (3km max. error) of the available lightning and D.E.M. data. Still, the null-hypothesis that lightning strikes occur randomly is accepted at these extents and resolutions.

### *4.6.0 Methods*

To explore the relationship between topographic orientation and forest cover type, the data layers expressing time-since-fire and dominant tree species were combined with data layers expressing topographic orientation classes (as defined before). This process created one mapsheet which retained the information of each data layer. To create a database of manageable size, rather than using the entire set of map cell attributes, the GRASS command *r.random*, was used to randomly chose 2300 (functional limit of statistical package) cells within the filter, or mask, of the forested landscape (see Fig. 4.2). The data per information layer per sampled point were converted into a text file and imported as a case-wise data set compatible with the SPSS statistical analysis format. Of the 2300 randomly sampled points, 62 points had corrupt data and were omitted from the data set prior to analysis.

#### *4.6.1 Discriminant Analysis*

Separate discriminant function analyses (D.F.A.) were conducted with dominant tree species and time-since-fire as response variables to delineate how predictable these attributes were using topographic measures. This process generated principal component axes which maximized the ability to discriminate between classed responses (Nie 1993) from environmental variables. Elevation (a.s.l.), local elevation, north-south exposure, east-west exposure, UTM Northing, UTM Easting and slope (all unclassified) were included as predictor variables. The compass directions of site exposure aspect were converted from the circular directional form into a linear gradient, ranging between 1 and -1, where:

$$\text{North/South Exposure} = (\cos(\text{Rad}\theta)) \qquad (1)$$

$$\text{East/West Exposure} = (\sin(\text{Rad}\theta)) \qquad (2)$$

The D.F.A. revealed different independent variables (orders of significance and correlation with principal component axes) associated with time-since-fire and canopy classifications. Predictive ability was barely greater than random. However, the principal component axes generated from the discriminant function analysis were used to guide further analyses and D.E.M. classifications. Subsequently, I conducted the following goodness-of-fit tests on canopy composition and time-since-fire distributions, classified by topography, to further examine potential landform influences.

### *4.6.2 Landform Classifications*

Two scales of landform classification were employed in this analysis. For the first coarse scale of observation the percent cover of the dominant tree species and time-since-fire distributions of the three elevation classes (class 3 above) were compared to that of the overall forest cover in the study area. The second, finer scale of observation, focused within each elevation slice by subdividing them into six landform classes (using 4, 7 and 9 above) including: *high and flat* (slopes < 2° and higher than the immediate landscape), *low and flat* (slopes < 2° and lower than the immediate landscape), *east facing* (slopes > 2° and with an exposure of 45 - 135°), *south facing* (slopes > 2° and with an exposure of 135 - 225°), *west facing* (slopes > 2° and with an exposure of 225 - 315°), and *north facing* (slopes > 2° and with an exposure of 315 - 45°).

The null hypothesis states that there was no topographic influence on long term fire frequency and/or behaviour. That is, there would be no difference between the overall time-since-fire distribution and that of landform classifications. To examine landform and tree species relationships, a null hypothesis stating that the spatial distribution of stands dominated by the various tree species was random was employed. This was used to examine the

differences between the distribution of tree species within the different landform classifications and the species distribution of the elevation slice.

The approach was intended to examine the spatial organization of the two forest attributes (age and dominant tree species). It was expected that the time-since-fire and species composition would similarly vary within the two scales of topographic classification. This expectation was based upon the conventional assumption that fire is the driving force of boreal forest succession and the specific fire history of a region strongly influences the mosaic of canopy composition of boreal landscapes.

The time-since-fire distributions of each of the three elevation profile slices, were tested for goodness-of-fit to the time-since-fire distribution of the entire study area. At the finer scale, within each elevation profile slice, the time-since-fire distributions of each of the landform classifications were tested for significant deviance from the time-since-fire distribution within the elevation slice in which it occurred. Because the data are 10yr aggregate classifications, and considered ordinal, the Kolmogorov-Smirnov non-parametric test goodness-of-fit (Sokal and Rohlf 1981, Zar 1984) was used. The distributions of dominant tree species, were similarly tested within the same elevation and landform classifications but G-tests (Sokal and Rohlf 1981) were used as such data are categorical.

## *4.7.0 Results*

### *4.7.1 Discriminant Analysis*

The topographic variables which were found to most strongly influence the pattern of dominant tree species were, in order of importance, slope class, local elevation, regional elevation, and north-south exposure (Table 4.1). Variables affecting the time-since-fire distribution are, in order of importance, regional

elevation, slope class and local elevation (Table 4.2). These variables are the basis for the principal component axes. The pooled within-group correlation of environmental variables with the principal component axes (Tables 4.3 & 4.4) show different configurations for forest age vs. composition.

**Table 4.1:** Summary of variables included in the step-wise regression (minimum tolerance to enter P=0.01) and discriminant function analysis of a forced canonical correspondence classification of the dominant tree species.

| Variable | Wilk's Lambda | P |
|---|---|---|
| Slope Class | 0.949 | <0.0001 |
| Local Elevation | 0.893 | <0.0001 |
| Regional Elevation | 0.866 | <0.0001 |
| North-South | 0.854 | <0.0001 |

**Table 4.2:** Summary of variables included in the step-wise regression (minimum tolerance to enter P=0.01) and discriminant function analysis of a forced canonical correspondence classification of the time-since-fire mosaic.

| Variable | Wilk's Lambda | Significance |
|---|---|---|
| Regional Elevation | 0.921 | <0.0001 |
| Local Elevation | 0.886 | <0.0001 |
| Slope Class | 0.856 | <0.0001 |

Although the amount of variation explained by each variable was significant (Tables 4.1 & 4.2), suggesting predictive relationships, the ability of the classification to predict time-since-fire and dominant tree species from the environmental variables was barely over that of random. The D.F.A. correctly predicted dominant tree species for 50.6% of the cases where a random selection was 48.8% correct. Similarly, the D.F.A. correctly predicted time-since-fire class for 19.05% of the cases where a random selection was 17.9% correct. Therefore, I did not continue modeling efforts. However, regional elevation was the variable most associated with variation in time-since-fire classes (Table 4.1), while it was the third most important variable, after slope class and local elevation, in explaining the variation in canopy composition (Table 4.2). These

suggestive relationships were then incorporated into the two different scales of topographic classification.

**Table 4.3:** The pooled within-group correlation between discriminating environmental variables and canonical discriminant functions derived from the best fit to tree species. *denotes largest absolute correlation between each variable and any discriminant function.

| Variable | Function 1 | Function 2 | Function 3 | Function 4 |
|---|---|---|---|---|
| Local Elevation | 0.236 | 0.883* | 0.801 | 0.389 |
| North-South | 0.232 | -0.301 | 0.839* | 0.389 |
| Northing | 0.174 | -0.218 | 0.299* | 0.235 |
| East-West | 0.007 | -0.045 | 0.088* | 0.038 |
| Slope Class | 0.641 | -0.398 | 0.069 | -0.653* |
| Regional Elevation | 0.493 | -0.249 | -0.525 | 0.647* |
| Easting | 0.027 | -0.007 | -0.041 | -0.096* |

**Table 4.4:** The pooled within-group correlation between discriminating environmental variables and canonical discriminant functions derived from the best fit to time-since-fire classifications. *denotes largest absolute correlation between each variable and any discriminant function.

| Variable | Function 1 | Function 2 | Function 3 |
|---|---|---|---|
| Regional Elevation | 0.858* | 0.198 | 0.473 |
| East-West | -0.014* | 0.009 | -0.005 |
| Slope Class | -0.411 | 0.775* | -0.479 |
| North-South | -0.014 | 0.100* | -0.021 |
| Northing | -0.001 | 0.099* | -0.048 |
| Easting | -0.022 | 0.056* | -0.054 |
| Local Elevation | -0.379 | 0.306 | 0.873* |

### *4.7.2 Regional Elevation*

The time-since-fire distributions of the lower third and the higher third elevation profile slices were significantly different ($\alpha$=0.01) from the overall time-since-fire distribution while the mid third slice was not (see Fig. 4.7). Comparisons of the distributions in Figure 4.7 show the time-since-fire distributions of the higher third have more younger forests while the low third of the landscape has more older forests. However, the distribution of tree species

of each elevation profile slice did not differ significantly from that of the overall study area (see Fig. 4.8, Fig. 4.10).

Across the entire study area, the age class distributions per tree species (see Fig. 4.10) show a appreciable amount of each species in all age classes between 1860 and 1950.

### *4.7.3 Finer Scale Landform*

In contrast to the correspondence of age and tree species distributions to regional elevation classes, the species composition of each topographic orientation (landform) class was significantly different ($\alpha$=0.01) from the overall distribution within the corresponding elevation profile slice from the distribution within the profile slice (see Table 4.7, Fig. 4.8). When I conducted this same comparison for the time-since-fire distributions all three elevation slices showed east facing slopes to be significantly different from the overall age pattern of the elevation slice (see Table 4.8, Fig. 4.6 & 4.7). In addition, the flat and low and south facing in the high elevation class, as well as the west and north facing within the low elevation class, had time-since-fire distributions that were significantly different form that within the elevation class.

**Table 4.5:** Results for each of the 3 elevation slices of the goodness-of-fit tests comparing species composition of each landform class, to the species composition of the overall area within a given elevation slice. All landform classes were significantly different ($\alpha$=0.01) than that of the elevation slice. n = the number of randomly sampled points within each class (analogous to relative area). $H_0$ - no difference between the distributions of the landform classification and that of the elevation class (high, mid, and low).

| | Landform Class | | | | | |
|---|---|---|---|---|---|---|
| | **flat and high** | **flat and low** | **south facing** | **west facing** | **north facing** | **east facing** |
| **high 1/3 $H_0$** | *rejected* | *rejected* | *rejected* | *rejected* | *rejected* | *rejected* |
| **n =** | 202 | 216 | 58 | 82 | 52 | 92 |
| **mid 1/3 $H_0$** | *rejected* | *rejected* | *rejected* | *rejected* | *rejected* | *rejected* |
| **n =** | 195 | 141 | 92 | 78 | 86 | 94 |
| **low 1/3 $H_0$** | *rejected* | *rejected* | *rejected* | *rejected* | *rejected* | *rejected* |
| **n =** | 111 | 123 | 126 | 192 | 113 | 193 |

**Table 4.6:** Results for each of the 3 elevation slices of the goodness-of-fit tests (Kolomogorov-Smirnov) comparing cumulative time-since-fire distribution of each landform class, to that of the overall area within a given elevation slice. n = the number of randomly sampled points within each class (analogous to relative area). $H_0$ - no difference between the distributions of the landform classification and that of the elevation class (high, mid, and low).

| | Landform Class | | | | | |
|---|---|---|---|---|---|---|
| | **flat and high** | **flat and low** | **south facing** | **west facing** | **north facing** | **east facing** |
| **high 1/3 $H_0$** | accepted | *rejected* | *rejected* | accepted | accepted | *rejected* |
| **n =** | 202 | 216 | 58 | 82 | 52 | 92 |
| **mid 1/3 $H_0$** | accepted | accepted | accepted | accepted | accepted | *rejected* |
| **n =** | 195 | 141 | 92 | 78 | 86 | 94 |
| **low 1/3 $H_0$** | accepted | accepted | accepted | *rejected* | *rejected* | *rejected* |
| **n =** | 111 | 123 | 126 | 192 | 113 | 193 |

Figure 4.8 shows the tree species composition classed by elevation slice and sub-classed by topographic orientation. The *flat and low* class of each elevation slice was the most different from the overall within-slice species distributions and is the only classification in which trembling aspen does not cover the most area. Further, white spruce dominates these *flat and low* areas at high and mid elevations where black spruce becomes dominant for the low elevations. Trembling aspen is the dominant species within the *flat and high, east facing, west facing, north facing* and *south facing* classes but its relative proportion decreases with lower elevations. Conversely, white spruce, the second most abundant species area-wise within the *flat and high, east facing, west facing, north facing* and *south facing* classes (excluding the *flat and high* class of the low elevation slice), increases in relative proportion in lower elevation classes. Balsam poplar appears to have a bi-modal distribution as its relative proportion is highest at low and high elevation slices. These general trends are apparent in Figure 4.8 but it is only when classed in a topographic context that they become significant.

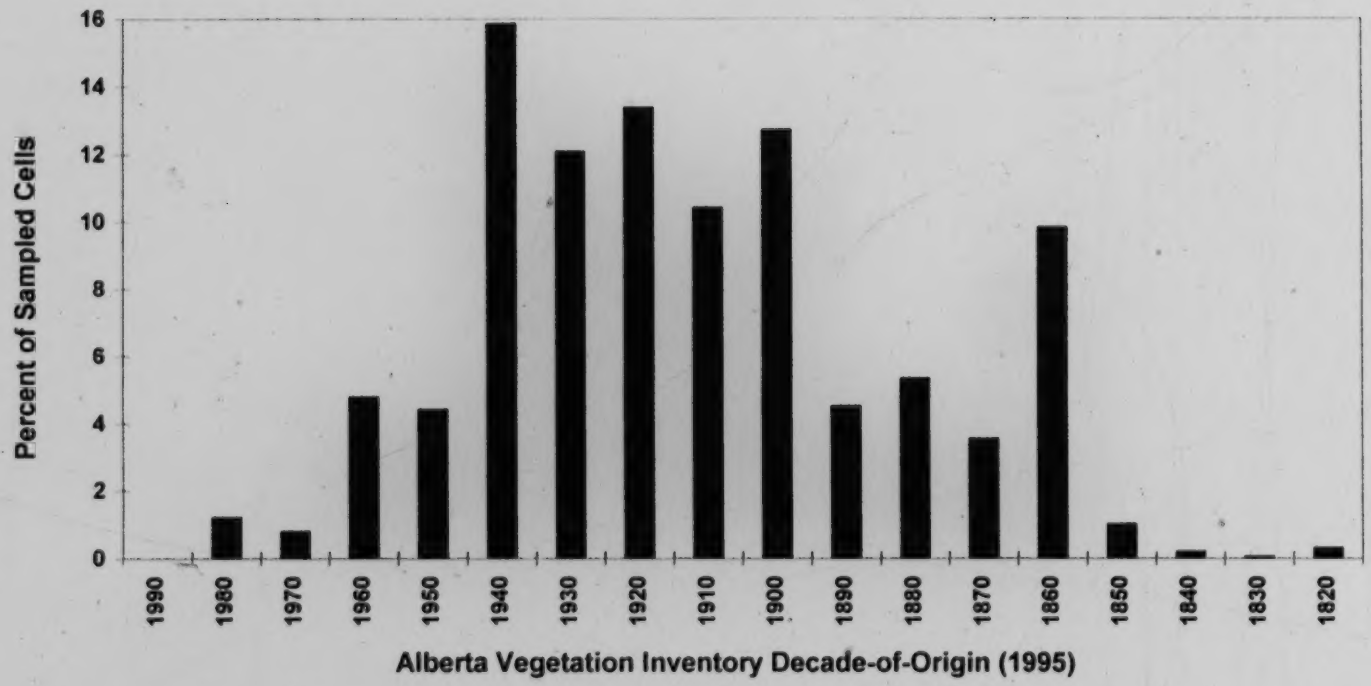



**Figure 4.6:** Time-since-fire distribution of the forested region near Calling Lake, Alberta (approx. 60,000 ha) as a proportion of 2238 cells randomly sampled from a digital landscape model. Distribution shows a punctuated age-class distribution indicating episodes of wildfire during the decades beginning in 1860, 1900, 1920, and 1940.

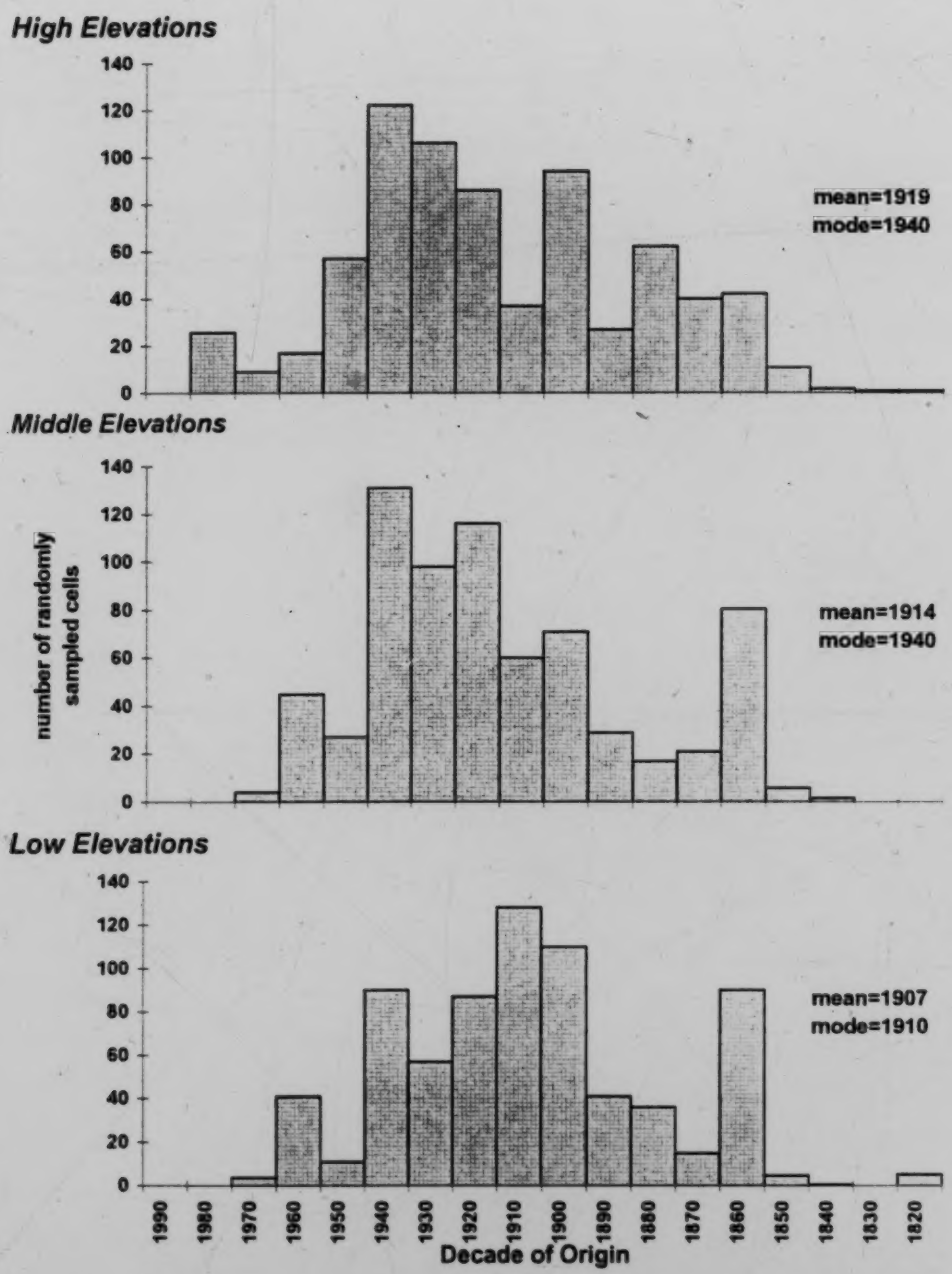



**Figure 4.7:** The timie-since-fire distribution of the study area near Calling Lake, Alberta classified into low, middle, and high elevaiton ranges. Each class represents about 20,000ha. The low and high time-since-fire distributions were significantly different ($\alpha$=0.01) from that of the entire landscape when tested for goddness-of-fit (Kolomogorov-Smirnov).

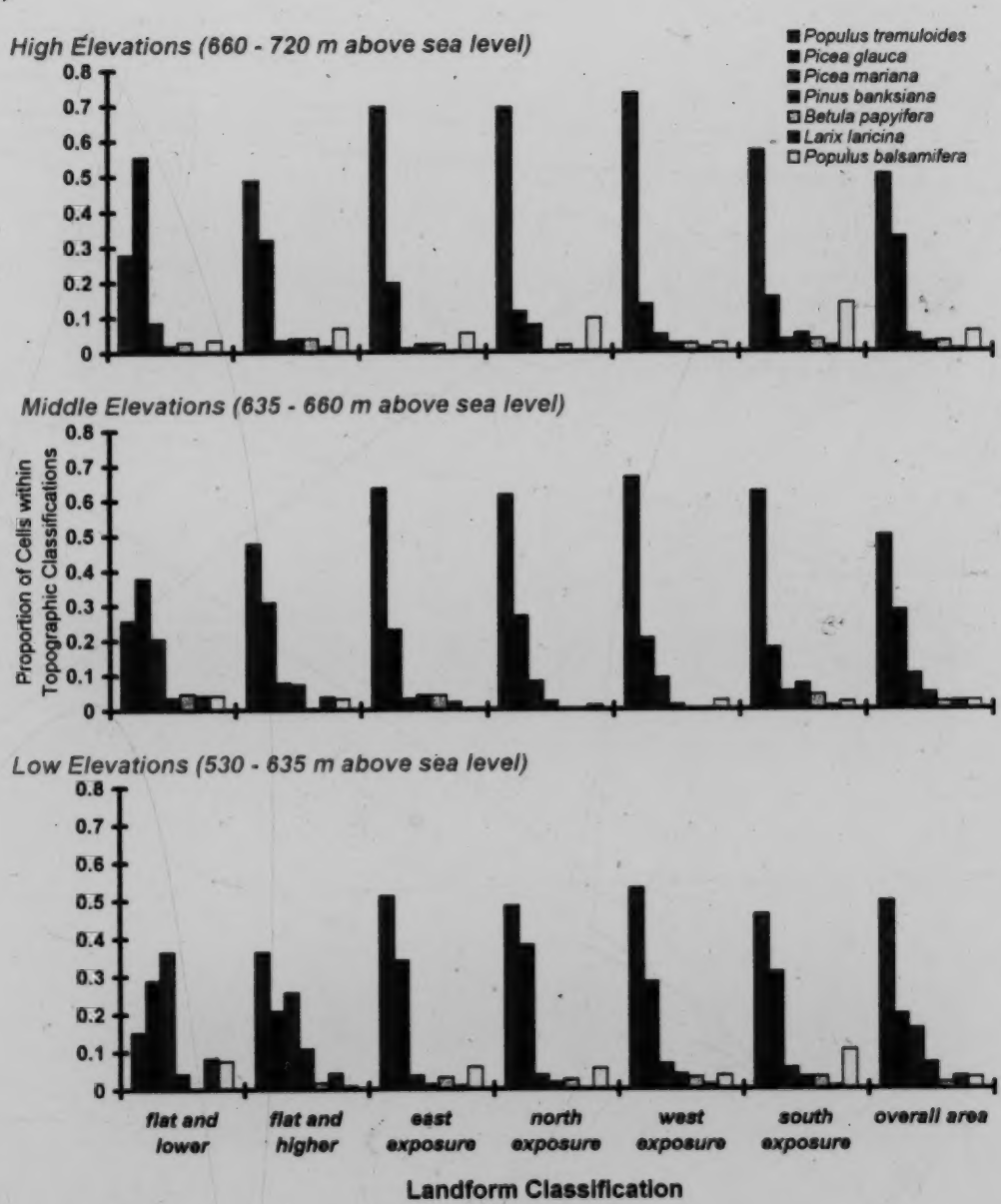



**Figure 4.8**: The dominant tree species grouped into three (low, mid, high) elevation classifications and sub-classified by landform. All distributions in the landform classes differ significantly (P= 0.01), using Kolmogorov-Smirnov tests, from the total canopy composition within the elevation class in which it occurs.

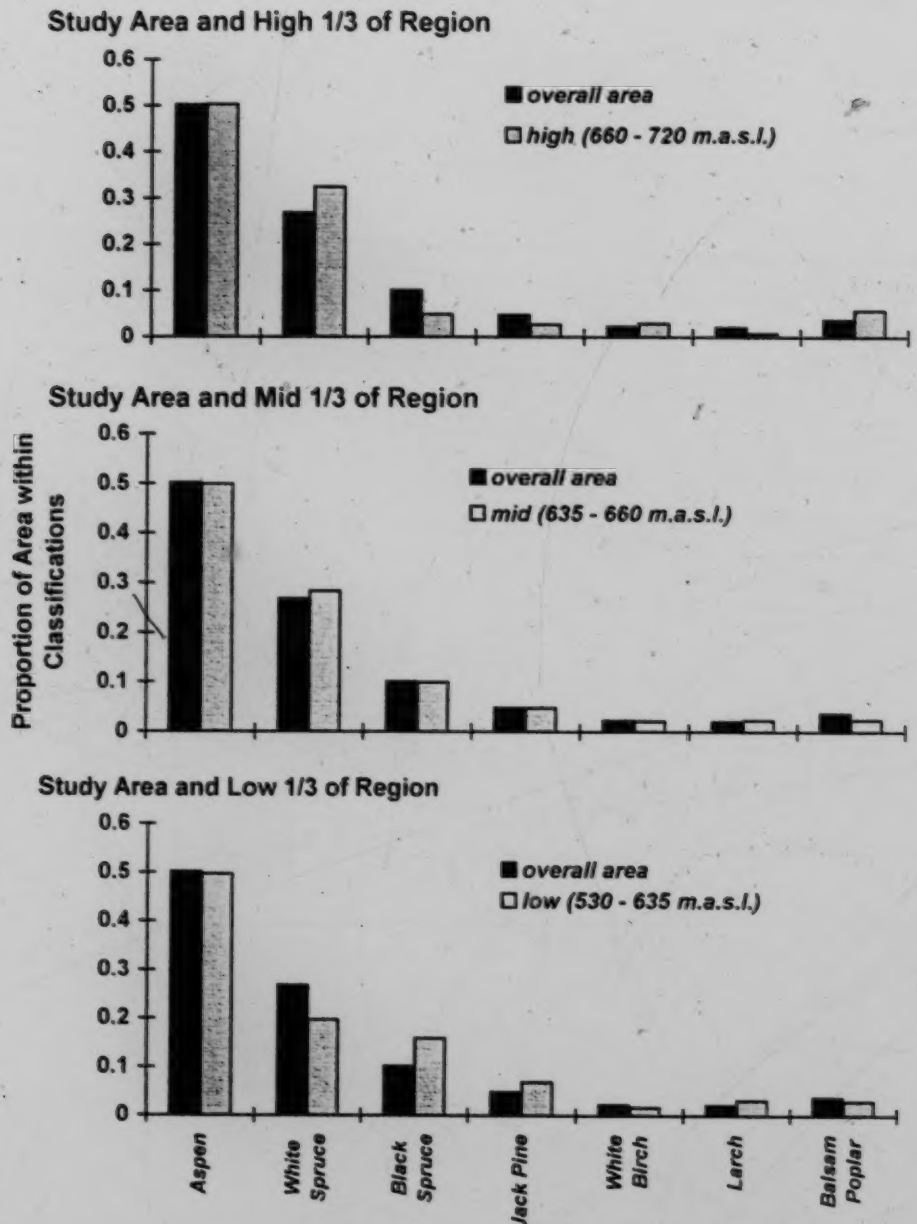



**Figure 4.9:** The distribution of area dominated per tree species for the three equal-area elevation classifications (high, mid, low) and that of the entire Calling Lake Study Area. None of the distributions within the elevation classes differed significantly from that of the entire study area.

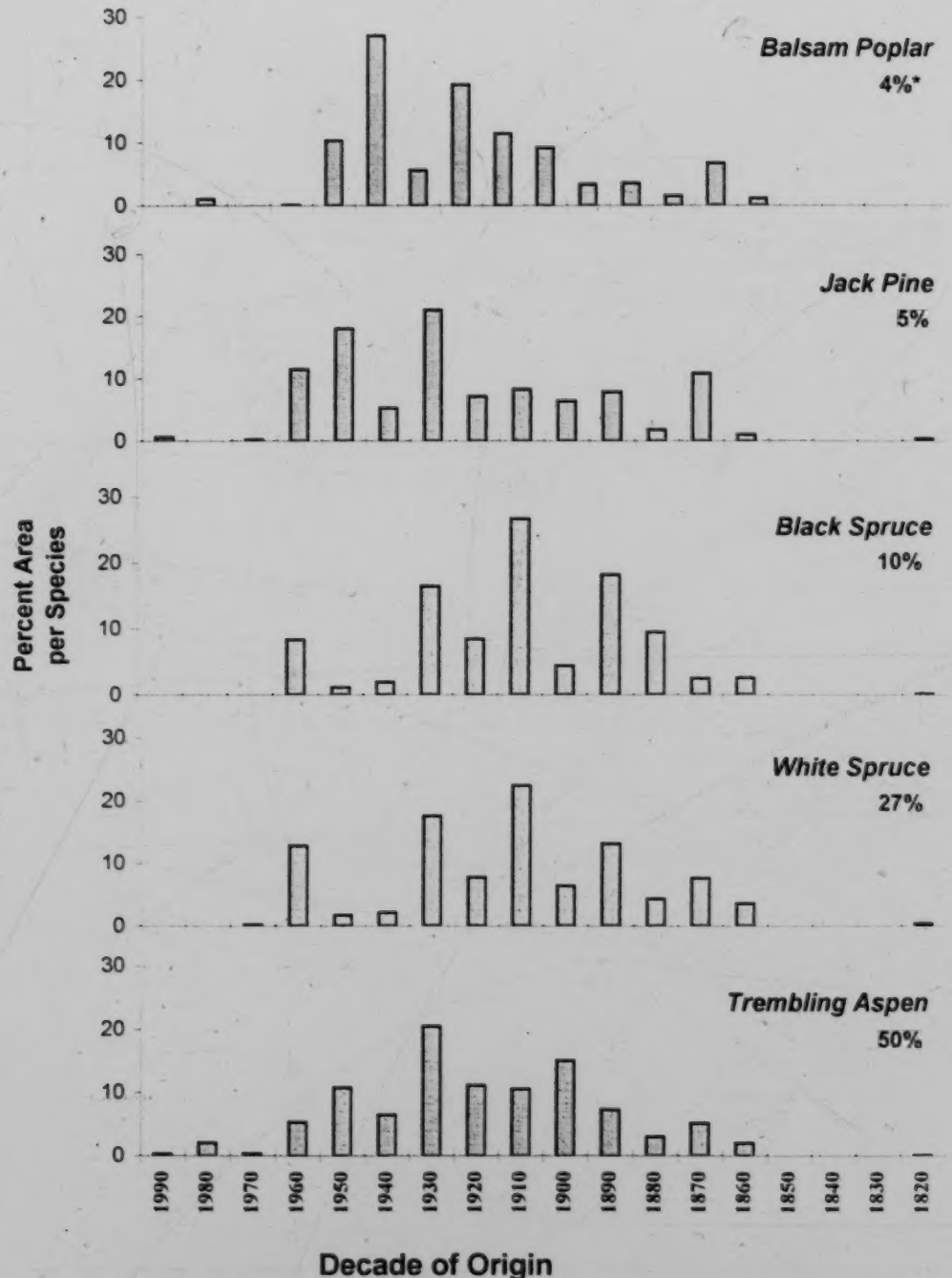



**Figure 4.10:** The proportional area age class distribution of the dominant canopy tree species in the Calling Lake, Alberta study area. *percent of forested landscape (~60,000ha) dominated by tree species.

### *4.8 Conclusions and Discussion*

The distributions of the time-since-fire and dominant tree species mosaics varied with topography at different scales of classification. This supports the discussions of Dix and Swan (1970) and the study of Suffling *et al.* (1988) that site conditions, not time since a natural disturbance, most influence boreal forest compositional development. The variance of time-since-fire was greatest when examined at a coarse scale of topographic classification, whereas variation of tree species composition was greatest within the finer scale of topographic classification. Regional elevation corresponded to changes in time-since-fire distributions, while localized elevation was more associated with canopy composition.

Taking these different scales of observation to be indicative of ecological organization, the results imply that the mechanism(s) producing the two patterns are also different. Thus, the distribution of tree species across the landscape may be more independent of fire history than generally assumed. Fire history appears to be more closely related to factors associated with regional elevation, whereas canopy dominance is associated with topographic variation and related factors at a local scale. This being the case, the occurrence of stand replacing fires in the study area (resolution considered) has been more influenced by topography than the fuel complex (i.e. the vegetation and community and structure represented by canopy tree species). Assuming that lightning, the primary ignition source, is spatially random at the scale used here. The long term fire history in this region appears to have been most dependent on patterns of regional topography.

Further, knowing that fire is the dominant disturbance in this region, post-disturbance successional development of forest canopy composition has been influenced significantly by local topographic position. This would not be the

expected pattern if time-since-fire was the dominant influence on successional development of canopy composition. This contradicts the traditional view of predictable successional development from aspen to white spruce dominated forests. This is supported by the similar age class distributions of the dominant tree species in the study area (see Fig. 4.9).

There are three large spikes in the landscape's time-since-fire distribution: the 1940 (57 y.s.f.), 1900 (97 y.s.f.) and 1860 (137 y.s.f.) decade-of-origin. This is the expected signature of a landscape which experiences episodic stand-replacing wildfires. The maintenance of the oldest time-since-fire spike on the landscape is greatly reduced in the high 1/3 of the landscape where the youngest time-since-fire spike in the landscape is most evident. Conversely, the mid 1/3 showed an intermediate time-since-fire distribution which maintained the signatures of all fire events represented in the entire study area.

Fire frequency can be spatially stratified using regional elevation patterns. Higher regions of a landscape experience stand replacing fires more frequently than lower regions. This becomes ecologically significant considering the mild relief of such boreal areas when compared to mountainous regions in which the influence of topography on fire frequency is more obvious. Considering that this subtle relationship can be found within a forested boreal landscape (~50,000ha), the time-since-fire mosaics of boreal regions cannot be considered entirely spatially random but to a degree spatially dependent on topography; specifically, regional elevation.

As such, the use of the cumulative distributions of age-classes as an assessment of temporal variation in fire history, without considering the topographic context and influence, is misleading at the scale at which planning, harvest operations, and/or resource management decisions are made. Between the time periods which experience extremely dry weather conditions and fire

events, fire frequency is dependent on elevation position. In this sense elevation is most likely an indirect measure of relative near-surface moisture and drainage levels. The correct size of the region needed to consider the "user-defined" maintenance of old-growth forest (see Johnson *et al.* 1995) is greatly reduced with the inclusion of topographic influence on long-term fire frequency.

### *4.9 Implications*

Presently, dominant models of boreal fire regimes (e.g. Johnson and Gutsell 1994) and ecosystem management strategies (see Hunter 1993, Johnson *et al.* 1995) are used to evaluate and discuss the rates and spatial configuration of commercial forest harvest (assuming that fire suppression is absolute) in Alberta. Such landscape interpretations and models are based on huge landscape extents and it is generally assumed that the underlying assumptions and conclusions are constant at all relevant scales. However, harvest operations, planning units, and regulations are designed and applied at much smaller spatial scales. The implications of relying on assumptions of spatially random fire occurrence, or homogeneous fire frequency, to regulate commercial forest harvest in boreal ecosystems seem too great not to be rigorously tested.

The paradigm that fire is the dominant force driving the distribution of tree species and succession of the boreal landscape may be overemphasized in conventional ecology and application. When compared to other forested regions, northern ecosystems have experienced constant and drastic change in the present post-glacial period (Pielou 1991). In this case, a steady-state non-equilibrium concept of ecological development (see Kay 1991) may be a more appropriate model to interpret boreal landscapes through time. This was supported by the findings of Cumming *et al.* (1996), who found no evidence of a

shifting steady-state forest mosaic (see Borman and Likens 1979) within western boreal mixedwood landscapes. Findings such as these support past arguments that simplistic theories of directional succession, reset by episodes of natural disturbances, are not adequate to describe the ecological development of mixedwood boreal landscapes (see Whittaker 1953, Rowe 1961, Dix and Swan 1971, Corns 1983, Galipeau *et al.* 1997).

Reliance on untested assumptions to justify harvest regulations does not err on the side of caution. If we harvest a landscape while embracing the spatially random model of fire occurrence, the oldest stands will be harvested first. Within a landscape that experiences spatially random fire event, stands are old, and have escaped fire, by chance alone. Older, more voluminous stands are generally harvested more often. Although forecasting may aim to provide representative age classes during the harvest rotations, there is a greater risk that the young stands will experience stand replacing fire, based on topographic orientation alone. Therefore, the amount of old stands left on the landscape may be significantly lower than forecasts estimate.

Older stands have "escaped" wildfire disturbances due to factors which include topography. Therefore, to harvest these areas under the pretense they have an increased fire hazard may unfounded. Also, by incorporating the assumption that fire disturbances are spatially random, and over-generalizing boreal forest succession across broad landscapes, even ecosystem-based harvest strategies may be selectively harvesting the inherent reserves of flora and fauna habitat of the boreal mixedwood landscape. These reserves may be critical landscape resources, or source populations, that are needed to maintain ecological integrity in lieu of future catastrophic disturbances; initiated by anthropogenic or ecological agents.

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# CHAPTER 5

## *Summary of Conclusions, Future Directions and Recommendations*

### *5.1 Synthesis*

When examined at a spatial resolution of 0.4ha and a temporal resolution of 10 years, western boreal mixedwood forests that are close to open water are not consistently different from the surrounding landscape in canopy composition or age. Rather, it is a waterbody's location, within the local and regional topography, that most corresponds with the probable age and canopy composition within 600m of water's edge. The time-since-fire distribution of a region is influenced by regional topographic position (approx. 60,000ha). That is, within a total elevation range of 230m higher regions tend to be younger while lower regions tend to be older. Local-scale topographic undulations, within 500m of a given location, influence canopy composition more than regional changes in elevation. Therefore, the mosaic of dominant tree species can be considered to be nested within, and possibly independent of, the time-since-fire mosaic. This study was conducted within areas similar in size to the 'Landscape Management Units' employed to plan and manage Alberta's forest resources. As such, this study may provide ecological information appropriate for application to efforts to develop more ecologically benign harvest strategies.

## *5.2 Summary of Conclusions*

The major observations, conclusions and recommendations are discussed in more detail and organized by Chapter below.

***Chapter 2***

Although the Alberta Vegetation Inventory is produced primarily for forest resource planning, it can be used as a reliable representation of the spatial pattern of time-since-fire classes across Alberta's western boreal landscapes. This alternative use of forest inventories can greatly improve the efficiency of future fire history studies if the specific accuracy of the A.V.I. age estimations is known, and additional ground checks are performed. If the Alberta Vegetation Inventory is to be used as indicative of true ecological associations, the spatial resolution of the forest cover data should be examined thoroughly.

Additionally, the distribution of age juxtapositions in the Calling Lake region of Alberta (Fig. 1.4), may be indicative of a spatially dependent time-since-fire mosaic. We may expect the distribution of time-since-fire juxtapositions (measured as edge length) across a landscape to be equidistant (i.e. relatively equal lengths of edge attributed to each age-difference class) if fire occurrences were spatially random. Hence, the observed juxtaposition pattern (Fig. 2.4) may suggest that time-since-fire mosaics were slightly clustered and/or were inherently organized.

As more detailed within-stand information is developed in the A.V.I., more extensive studies of landscape patterns of community and edaphic associations can be developed through ecological research and should be explored for management applications (see Rettie *et al.* in press. as an example).

***Chapter 3***

Forests adjacent to lakes do not exhibit a unique canopy composition or time-since-fire distributions when compared to local "upland" areas at landscape scales. At a resolution of ~0.4ha; regions around moderately sized lakes do not consistently harbour stands that are older than those in the surrounding landscape. Nor do these riparian regions consistently differ from the surrounding forest in the amount of trembling aspen or white spruce. The ecological setting as described by regional elevation, local landform and/or surface geology is likely to better predict unique or specific canopy composition and/or wildfire history than distance to open water.

***Chapter 4***

Topography has a differential influence on the time-since-fire and tree species distributions within western mixedwood boreal landscapes. Although the temporal distribution of fire occurrences is determined by climatic variation (Johnson 1992) the spatial arrangement of time-since-fire classifications is associated with topographic position. Therefore, the long-term spatial arrangement of stand-replacing fires is, to some extent, dependent on topographic position in mixedwood boreal landscapes.

The spatial mosaic of dominant tree species is associated with a finer spatial scale of topographic undulation than that of time-since-fire distributions. This would support suggestions that, although a specific fire event may be influenced by fuel type juxtapositions, the long-term history of stand-replacing fires is not related to fuel type. In addition, the species composition of forest canopy is not an accurate reflection of time-since-fire.

Based on landform classifications, 'signatures' of past fire events/years are seen as spikes within the time-since-fire distribution (see Fig. 4.7). Within the boundaries of landforms that are *higher and drier* than the rest of the landscape, we have a reduced ability to detect historical fire events. This is usually the case

for fire history studies because the most recent fire events have burned the evidence of previous fire events. In contrast, landform classifications that are *lower and wetter* than the surrounding landscape may preserve evidence of past, and relatively expansive, fire events.

Forests which occur in regionally lower, and potentially wetter, areas may reflect the history of intense and large wildfire events. Due to a lower ignition potential and fire spread conditions, the *lower and wetter* regions may 'remember' older fire history information. Such a relatively 'deeper' fire history can be considered indicative of a long-term fire regime (an approximate return interval of at least 160-300yrs) of temporally episodic and intense fire events. In contrast, the time-since-fire distribution of the *higher and drier* areas may be more indicative of a less extreme, more frequent fire regime (an approximate return interval of 50-150yrs) of a region.

There is increasing evidence that wildfire history is affected by landform (see Francis 1996, Andison 1997). Therefore, we cannot consider long-term wildfire occurrences to be spatially random. Nor can we rely on models, which assume fire occurrences and theoretical frequency to be spatially random, to guide harvest rotation plans. Rather, to some degree fire frequency is location specific with respect to regional elevation. Using time-since-fire distributions to assess the fire regime and/or fire return interval of a region is misleading if generalized across broad landscapes without incorporating regional spatial influences (i.e. topography). Given this potential for relative fire frequency, the correct size of the region needed to consider the "user-defined" maintenance of old-growth forest (see Johnson *et al.* 1995) is greatly reduced with the inclusion of topographic influence on long-term fire frequency.

Reliance on untested assumptions to justify harvest regulations does not err on the side of caution. If we harvest a landscape while embracing the spatially random model of fire occurrence, the oldest, most voluminous stands

will be harvested first and removed from the landscape. Although forecasting scenarios may strive to provide representative age classes during the harvest rotations, there is a greater risk that the young stands will experience stand replacing fire, based on topographic orientation alone. Therefore, the amount of old stands left on the landscape may become significantly lower than forecasts estimate.

Older stands have "escaped" wildfire disturbances due to factors which include topography. Therefore, to harvest these areas under the pretense of utilizing the resource because of an increased fire hazard may be a false perception. By incorporating the assumption that fire disturbances are spatially random, and over-generalizing boreal forest succession across broad landscapes, even ecosystem-based harvest strategies may be selectively harvesting the inherent reserves of flora and fauna of the boreal mixedwood landscape. These reserves may be critical landscape resources, or source populations, that are needed to maintain ecological integrity in lieu of future catastrophic disturbances initiated by anthropogenic or ecological agents.

### *5.3 Future Directions and Applications*

Commitments to ecologically-based forest management must explicitly acknowledge a lack of understanding of forested ecosystems and inherent natural disturbances. It is, therefore, assumed that all practices concerning forest resource extraction, allocation and planning are subject to change in order to incorporate more direct, current, applied, and integrative information. Considering the potential that multi-layered, nested, and spatially explicit studies provide regarding landscape interpretations of forested ecosystems, resource planning and extraction practices should be able to readily incorporate such

information to ensure that short and long-term forest changes induced by harvest practices err on the side of caution.

A continued effort to piece together an understanding of landscape pattern, throughout history, across landscapes, and into the predictable future, is essential if our evaluations of forest use and subsequent change are to be effective. Pursuing this scenario, studies should be conducted at spatial scales relevant to the question being evaluated. This would help ensure that evaluations and improvements of related planning and management activities are based upon appropriate information.

To this end, I recommend that future research in the western boreal mixedwood consider:

*1)* A further examination of wildfire behaviour and regimes of boreal mixedwood landscapes, using various extents and resolutions of information to define, in more detail, the amount topographic influence on spatially explicit interpretations of fire regimes and behaviour.

*2)* A further exploration of the possible association between lightning strikes and landform. Many different extents and resolutions would be necessary to define the scale(s) of correspondence.

*3)* A more specific exploration of differential fire frequency-landform associations. This would require very detailed elevation and forest cover information.

*4)* The specific arrangement of boreal forested landscapes, paying close attention to juxtaposition (age and canopy) in relation to proportional cover per class, in order to assess the specific organization and spatial pattern of boreal landscapes. Such a study is readily achievable with existing data and GIS capabilities.

*5)* A more comprehensive account and assessment of mixedwood boreal landscapes by spatio-temporally nesting interpretations of all natural disturbances and canopy patterns which occur across such landscapes. For example, windthrow, forest pathology, insect damage, and flooding, occur between stand-replacing fire events and may also be closely related to topography. These disturbances

may have more influence on canopy composition and community development, than wildfire and disturbances.

*6)* Broad and fine scale examinations of the wildfire histories within and between different biogeoclimatic zones, micro-climates, landform classifications, weather patterns and lightning patterns, to determine the specific spatial tendencies and organizations which occur across Alberta's forested landscape. Such a synthesis of available information could serve as broad scale ecological information to guide forest harvest planning and regulations.

*7)* A more detailed assessment of riparian forest and forests surrounding drainage corridors (e.g. near-surface ground water channels, streams and rivers). This may produce different patterns than the forests around lakes in western boreal mixedwood landscapes.

### *5.4 Recommendations*

*1)* Based on this study, riparian buffer-strips around lakes should not be considered incidental reserves of unique forest canopy attributes nor old-growth forest attributes across the mixedwood boreal landscape. Rather, it is a lake's position within forest patterns and processes, that become apparent at broader extents of observation, that determines the probable time-since-fire distribution and canopy composition and should be incorporated into harvest planning efforts. The regulations regarding post-harvest buffer-strips surrounding moderately sized lakes should focus on movement corridors, erosion control, aquatic ecosystems, and water balance (local and regional) in boreal regions, rather than as incidental preserves of regionally unique forests. It should be noted that this study was conducted at a specific extent and resolution of information.

*2)* It is doubtful that wildfires occurring during extreme weather conditions can be substantially retarded by suppression effort alone. As such, harvest operations which emulate severe fire events are additive disturbances for a landscape to absorb. On the landbase managed for forest harvest in Alberta, I suggest that harvest rotations be designed to emulate the disturbance type, severity and frequency which dominates the specific stand type and ecological setting between the estimated periodicity of major fire/disturbance events.

Such an effort should initially apply spatial patterns, topographic orientation, and possibly surface geology, to stratify disturbance regime assessments, harvest scenarios and different planning activities. It may be reasonable to consider that the fire history or regime of a region expresses dichotomous time-since-fire signatures. I describe these two classes of fire regime as; *1)* extreme fire events/weather, and *2)* fire events which occur between extreme fire events ignited in extreme weather conditions and therefore notably harder to control. This being the case, such plans should adopt differential harvest rotations and activities.

*3)* This study focused on an area similar in size to those employed in present forest resource planning activities in Alberta (e.g. Landscape Management Units). Applied studies should make efforts to use a resolution appropriate for the different disturbance types and resource/harvest planning scenarios that are proposed. Planning efforts should utilize ecological information and interpretations that have been derived from studies which employ observational scales relevant to the intended operations and strategies. Such ecological data should be used to evaluate the basis of harvest techniques and plans.

*4)* A dependence on one ecological process as an 'umbrella' to ensure that recent and future actions will maintain long-term ecosystem functions, biological diversity and ecological integrity is intuitively naive. The argument that there is a real possibility that different processes determine age distributions and canopy composition across a forest would dispute such a strategy. Ecosystem management in western boreal mixedwood ecosystems should incorporate all disturbance regimes, between and within different disturbances caused by various agents (e.g. disease, insects, blow-down, flood, fire), into evaluations of harvest strategies. The true result of fire suppression activities, and the long-term tendencies of fire across a landscape should be specifically addressed. Additionally, multi-scale parameters should be incorporated without one scale and/or pattern type considered the dominant.

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